COMMON COMMODITIES AND INDUSTRIES

INCANDESCENT LIGHTING

S. I. Levy

(1457B)

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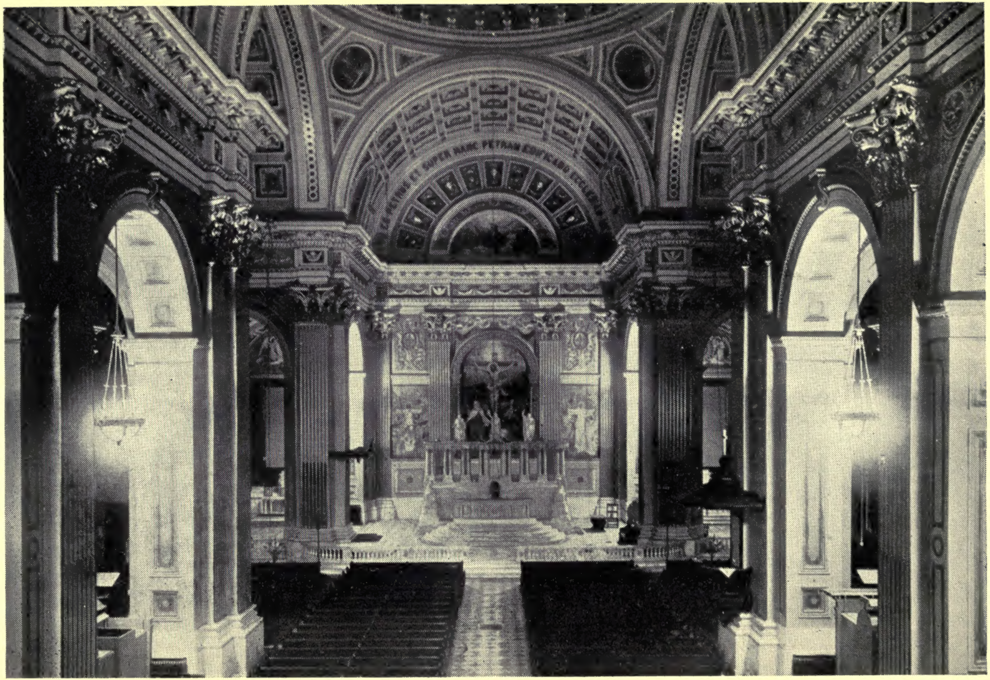

Frontispiece

PLATE NO. 1

THE HIGH ALTAR, CATHEDRAL OF ST. PETER AND ST. PAUL, PHILADELPHIA
Illuminated by the Suspended Inverted Incandescent System

(1457B)

PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

INCANDESCENT LIGHTING

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PREFACE

THE subject of Incandescent Lighting is itself extensive, and is closely related to several others of great interest. In endeavouring to give a general account in so small a compass, it has been necessary to make the treatment both concise and selective. Attention has been given primarily to the mining and treatment of monazite, and the manufacture of the mantle, but an attempt has been made to bring the whole subject under review, and to describe and compare the different methods of lighting now in use. The comparative treatment has been historical as well as general, and deals particularly with considerations of cost, and of efficiency from the energy point of view.

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S. I. LEVY.

SORBO WORKS,
WOKING,
April, 1922

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ILLUSTRATIONS

INCANDESCENT LIGHTING

CHAPTER I

THE DEVELOPMENT OF ARTIFICIAL LIGHTING

(*a*) **Early Methods of Lighting.** The origin of fire, which must have provided man with the first light he was able to obtain beyond that of the sun and moon and other heavenly bodies, can be traced far back to the earliest history of man, beyond even the history of Neolithic man, from whom the ancestors of all the known civilizations of the world were descended. The lower men of the Neanderthal age, who disappeared with the advent of our Neolithic ancestors, some thirty thousand years ago, were certainly familiar with fire. During the last ice age, which began in Western Europe somewhere about eighty thousand years ago, and ended about thirty thousand years ago, Neanderthal man took shelter in rock caves, in which he kept fires burning for warmth and light, and as a protection against wild beasts. Remains of this period scattered over Western Europe contain charred bones and fragments which show clearly that fires were generally used. Pieces of flint struck against fragments of pyrites appear to have afforded the means of obtaining sparks, from which, doubtless, dried wood shavings or leaves were ignited, and the fire once started was probably kept going continually. Pieces of dried wood ignited at the fire

probably supplied torches, which enabled the more adventurous individuals to explore the recesses of the caverns in which they lived.

The great value of fire to mankind for purposes of warmth and defence, and as a means of light, doubtless caused it to be regarded with peculiar veneration, and made it a symbol of great religious significance. In all religions light has been, and remains, the symbol of joy and of life-giving power, whilst fire, the producer of light and heat, became sacred to all the earlier civilizations. The Parsis worship Ahura Mazda, the sun god. The Brahmins hold a special festival to Lakhshni, the goddess of prosperity, in which lights play a great part ; the Egyptians elaborated the cult of Isis, in whose honour lamps were burned by day. The six-branched candlestick burning before the Holy of Holies, and the lamp kept continuously burning before the Ark, show the importance of fire and light as religious symbols to the Jews, and this significance passed into Christianity. The Greeks kept a golden lamp burning continuously before the temple of Athena—the Phoenicians buried lamps with their dead—the Romans worshipped their household gods with lamps and candles. All these religious observances must have arisen from the great importance of fire in the history of the development of man.

Wood and later coal fires remained, as far as can be discovered, the sole sources of light until well into historical times. The use of beacon fires of wood for signalling and illumination is first mentioned about 660 B.C. The celebrated Pharos of Alexandria, the first lighthouse building, was erected about 250 B.C., and was merely a permanent beacon fire kept burning at the top of a tower ; this method of lighthouse illumination was not improved upon until the eighteenth

century of the present era. The great Roman naturalist, Pliny the Elder, who was killed whilst observing too closely the great eruption of Vesuvius which destroyed the towns of Pompeii and Herculaneum in the year A.D. 70, mentions the use of oil in Sicily for illumination. This oil was probably petroleum, but the use of animal and vegetable fats and oils in lamps must certainly have been practised in much earlier times. The candlesticks of Biblical times were in reality lamp-holders, and there is evidence that lamps were used by the earliest civilizations of which we have records. They were made and used freely by the Greeks, and many beautiful specimens in bronze, symbolic of various phases of Grecian art, are preserved in our museums.

These early lamps were merely shallow dishes of clay or earthenware, with a short wick protruding from a spout, or through a hole in the wall. Various kinds of fat were probably employed in them according to local conditions, but during the Middle Ages the oils most generally used seem to have been colza oil, obtained from the seed of the colza, a variety of cabbage, and sperm oil, obtained from the cachalot or sperm whale. These lamps must have had very small illuminating power only ; the flames were very smoky and variable, and choking fumes were evolved, so that in confined spaces the effects must have been very unpleasant. Such as they were, however, they remained practically the only source of illumination available, besides wood and coal fires, until the Middle Ages. Tapers and candles began to come into general use about the fifteenth century, though wax lights, probably made from beeswax, were used by the Romans. Wax candles were relatively expensive, and were employed only in the houses of the wealthy, and in religious observances. For ordinary purposes, rush-lights, obtained simply by

removing the outer tissues from common rushes, found considerable employment. There were already in existence in Paris in the thirteenth century two guilds of candle-makers—the first guild made wax candles, whilst members of the second went from house to house to make tallow candles for the inhabitants. Similarly two livery companies, that of the Waxchandlers and that of the Tallowchandlers, developed in London. Tallow candles were used to illuminate Smeaton's Eddystone Lighthouse, built between 1756 and 1759. This was the first dovetail-jointed stone structure erected, and formed the model from which later lighthouse design has developed. Its light was furnished by twenty-four tallow candles, each weighing two-fifths of a pound, and each equivalent to 2·8 standard candles, giving the imposing total of 67·2 candle-power. The standard candle, which serves in England as the unit of illuminating power, is a sperm candle, weighing one-sixth of a pound, consuming 120 grains of spermaceti per hour. Sperm wax came into use for candle-making about the middle of the eighteenth century, and paraffin wax about the middle of the nineteenth. Nowadays candles are made from various mixtures of these waxes, and are provided with plaited wicks, which obviate the trouble of snuffing or trimming the end of the wick ; as the candle burns, the twist on the fibres of the wick continuously brings the free end into the flame, so that it burns away.

An interesting account of the state of illumination at night in London in the middle of the eighteenth century is given by Dickens in his novel *Barnaby Rudge*. The year in which the action of the novel is placed is 1755—

" A series of pictures representing the streets of London in the night, even at the comparatively recent

date of this tale, would present to the eye something so very different in character from the reality which is witnessed in these times that it would be difficult for the beholder to recognize his most familiar walks in the altered aspect of little more than half-a-century ago.

" They were, one and all, from the broadest and best to the narrowest and least frequented, very dark. The oil and cotton lamps, though regularly trimmed twice or thrice in the long winter nights, burned feebly at the best ; and at a late hour, when they were unassisted by the lamps and candles in the shops, cast but a narrow track of doubtful light upon the footway, leaving the projecting doors and housefronts in the deepest gloom. Many of the courts and lanes were left in total darkness ; those of the meaner sort, where one glimmering light twinkled for a score of houses, being favoured in no slight degree. Even in these places the inhabitants had often good reason for extinguishing their lamp as soon as it was lighted ; and the watch being utterly inefficient and powerless to prevent them, they did so at their pleasure. Thus, in the lightest thoroughfares, there was at every turn some obscure and dangerous spot whither a thief might fly for shelter and few would care to follow ; and the city being belted round by fields, green lanes, waste grounds, and lonely roads, dividing it at that time from the suburbs which have joined it since, escape, even where the pursuit was hot, was rendered easy."

(*b*) **Development of the Oil Lamp.** The first important improvement on the primitive methods of artificial lighting which had prevailed from the earliest historical times until the eighteenth century was the invention by a Frenchman, Ami Argand, in 1784, of the lamp which bears his name. In this lamp, a circular wick was

employed, held between two metal tubes. Below the top of these metal tubes, which constituted the burner, a perforated platform was placed round the lamp, supporting a glass chimney. This chimney, by causing the heated gases produced by the flame to rise straight upwards, created a suction which drew fresh air into the flame through the perforations in the platform. Air was also drawn through the inner tube of the burner into the middle of the flame, and greatly improved the combustion. In this lamp, for the first time, a clear, steady, smokeless flame was produced and the way was pointed out for further developments. Practically all the later oil lamps followed very closely the general design of Argand, modifications arising chiefly in the improvements of the chimney and the wick, and of the kind of oil employed.

The straight glass chimney was replaced first by a chimney having a shoulder somewhat above the top of the flame, so that the upper part was considerably narrower than the lower. Later the bottom of the chimney was rounded out in the form of a bulb or globe, and the lower edges were serrated or perforated to allow of easier access of air. Such forms of chimney are in common use to-day. The wick and its holder have assumed various forms, without any essential alterations. Its function is to give a correct and constant quantity of oil to the flame, so that complete combustion may always take place, and the flame burn steadily and clearly, without smoking or flickering. As the oil is sucked up to the flame by the capillary action of the fibres of the wick, it is necessary to use a long staple cotton of good quality, with the smallest possible twist in spinning, so as to allow a free uniform passage to the oil. The fibres of the wick act as filters for any foreign matter in the oil, so that the wick becomes

clogged sooner or later, according to the purity of the oil used, and must be discarded. The original circular or tubular wick of Argand is still very generally used, but flat wicks are also common. In 1865 Hinks introduced his "Duplex" burner, in which two flat wicks are used, whilst in 1868 Doty employed a multiple wick burner. The flat wick lamps are generally employed where a relatively low illumination, say from 10 to 25 candle-power is required, whilst the circular wick, though quite satisfactory also for moderate powers, can be employed for more powerful lamps. The Doty multiple wick lamp has been used in lighthouses.

Modifications in the burner itself, with a view to producing more even distribution of the air to be consumed, are very numerous. They consist chiefly in the introduction of small perforated plates, buttons of metal, corrugated or bent discs, etc., both below and above the burner. Such plates are very commonly placed above the burners of lamps having circular wicks, and improve the combustion by directing the air sucked up through the inner tube of the burner outwards against the inner wall of the flame.

Before the introduction of petroleum, the heavy and viscous character of the oils employed rendered it necessary to have some means of securing a steady supply of oil to the wick in all except the smallest lamps. In the early years of the nineteenth century, many devices were suggested for this purpose, and lamps were frequently made with strong airtight reservoirs into which air was pumped to supply the pressure necessary to drive the oil freely to the wick. A common pattern was that in which a separate oil reservoir was placed above the body of the lamp, communicating with it by means of a metal tube down which the oil

flowed. A form which became very popular was devised by a Frenchman named Franchot, in 1836, under the name of the " Moderator " lamp. This contained an oil reservoir below the burner, the oil being driven by means of a spring acting on a piston inside the receiver up a narrow tube to the burner. The tube was in two sections, the lower moving inside the upper with the movement of the piston, and so arranged that the amount of oil reaching the burner was kept uniform.

(*c*) **Modern Oil Lamps.** The high cost of colza and sperm oils, and the necessity of some device in the lamp to ensure a supply of these heavy viscous liquids to the wick, were serious drawbacks to the general use of lamps. Towards the end of the eighteenth century, the use of naphtha was proposed, and early in the nineteenth century the light oils obtained from coal tar distillation, then in its infancy, were used in lamps of the Halliday type. This lamp consisted of a cylindrical oil reservoir, with a cone-shaped bottom, terminating in a vertical tube, at the lower end of which was a burner of the " Rose " type, a metal ring with many small perforations round the circumference. On turning a tap below the reservoir, the naphtha flowed down the tube to the burner, and was ignited as it escaped from the jets ; the heat of the flame caused the naphtha travelling down the tube to vaporize, and the vapour issuing from the jets in the ring burned with a very hot and bright, though smoky flame. The lamp was troublesome to ignite, and much naphtha might be wasted before the flame could be made to burn properly ; these disadvantages, together with the smoke, smell and heat, made it unpopular for many purposes, but it was largely used where a cheap form of light was required, as on hawkers' barrows, in circus tents and travelling shows, and so on.

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The introduction of petroleum, about the middle of the nineteenth century, marked the next great advance in illumination by lamps. Mineral oil, natural gas, and bitumen had been observed and remarked on from the earliest times, and various grades of petroleum (the name is derived from the Latin *petra*, a rock, and *oleum*, oil) had been used as embrocations and cures for various ills throughout the present era. Pliny remarked on the occurrence of oil in Sicily, and many observers recorded similar occurrences in Asia and Europe throughout the Middle Ages. Sir Walter Raleigh described the "Pitch Lake" of Trinidad in 1595, and the Oil Springs of Pennsylvania were known in Europe in 1748. It was not, however, until 1849 that James Young began the systematic treatment of mineral oils for commercial purposes, using a process of distillation which he covered by patent in 1850. His work began with an examination of an exudation of oil in Riddings Colliery, Alfreton, in Derbyshire, which on distillation was found to yield an excellent lubricating oil. Young erected a still to treat this oil, but the supply was soon exhausted. In searching for other sources of a similar material, he discovered that an oil could be obtained by distilling the Bathgate stone or shale, which occurs in large deposits in the Lothian districts, and in 1850 the Scottish Shale Oil industry was inaugurated. As only the lubricating oil was wanted, the lower boiling oil, which was found to be too light and mobile for lubricating purposes, was sold at very low prices as a waste product. It was discovered eventually that this was being bought for shipment to Hamburg, whence it was sent to Berlin for burning in lamps which were designed and manufactured by one Stohwasser. Young obtained a lamp, and had similar ones made by Laidlaw in Edinburgh, thus creating a demand

for light petroleum oil (paraffin oil or kerosene) for lighting.

The effect of Young's work was soon felt outside England. In 1854 the Pennsylvania Rock Oil Company was formed in America, but was unsuccessful. In 1859 its promoter, a Colonel Drake, formed the Seneca Oil Company, and struck oil at a depth of 69 ft. at Oil Creek, Pennsylvania—this well yielded at the rate of 25 barrels a day. A wild scramble for oil followed—besides the Pennsylvania region, oil wells were sunk in Virginia, Texas, Kentucky, Kansas, Tennessee, Illinois, and later in other states. The development was wonderfully quick—the output rose from 2,000 barrels in 1859 to more than 200,000,000 barrels in 1912, and it is still expanding rapidly. In other of the world's great oil-bearing districts, development has been variable. The Baku field in Russia was opened up in 1870; the first well was a "gusher," and proved unmanageable, over ten million gallons of oil being lost before the flow could be controlled. An enormous column of oil and sand was forced up from the well in a fountain-like formation which remained for some fifteen days; the whole district was covered with oil, which formed a vast lake, and eventually overflowed to the sea, whilst houses two miles away were drenched with the oil and covered with oily sand. This Baku field reached its maximum production between 1898 and 1901, yielding in these years about half the total world's supply, but its output has steadily fallen since. Galicia and Rumania were opened up in 1878 and 1880 respectively—in these districts very deep wells have to be sunk, and greater depths are continually necessary to get good results. From 1883 to 1890 the Dutch East Indies were brought in, and Sumatra, Java and Borneo are now important producers. Burma was

opened up for oil in 1890, whilst Mexico and Persia have only recently been added to the list of important oil countries.

The cheapness of petroleum, combined with its remarkable mobility and freedom from dirt and impurities, made it an ideal burning oil for lamps, in which it was now possible to do away with additional reservoirs, air-pumps and similar devices for forcing the air to the burners, since petroleum oils are readily drawn up by the wick. Petroleum oil lamps have been largely used in lighthouses, generally in the Doty multiple-wick burner. The Benson-Lee lamp, a paraffin lamp in which a carbon-tipped wick needing no trimming is employed, is a favourite pattern for untended coast lights; lamps of up to 1,000 candle-power can be designed to burn for several months without attention. Paraffin lamps are also used for heating, great variety of design being employed. In the Wells light, the forerunner of the now well-known "Primus" lamp, the oil is forced by air pressure through passages heated by the flame, in which it is vaporized, and from which it issues as an air-vapour mixture which burns with a very hot flame. In 1885 the Kitson lamp was patented—in this an oil vapour-air flame produced as in the Wells light was used to heat a platinum mantle to incandescence. This lamp was unsuccessful, but the introduction of the Welsbach mantle in 1893 opened up further possibilities in this direction. The application of incandescent lighting to oil lamps, however, is more fittingly discussed after an account of the incandescent mantle itself.

(*d*) **Coal Gas as an Illuminant.** So common and so necessary is the use of coal gas nowadays for domestic lighting and heating, that it is difficult to realize that it is little more than a century since the first attempt

was made to employ it. Although wood and coal fires have been used by man for many tens of thousands of years, and must have been used by the Greeks and Romans and other cultured peoples, it was not until the year 1600 that it was observed that gas could be obtained from coal or wood by heating. Until that date, indeed, the possibility of the existence of any kind of gas seems only vaguely to have been realized—the Dutch chemist Van Helmont described his discovery of coal gas in that year in language which shows this. Coal, when heated, he said, "Did belch forth a wild spirit or breath"; the Dutch word "Geest," meaning spirit, is believed by some to have been the source of our word gas, now the same in both languages.

Van Helmont's discovery attracted little attention, and it was not until some sixty or seventy years afterwards that his experiment was repeated by the Rev. Dr. John Clayton, who heated coal and collected the gas given off in bladders, finding it to be combustible. A century after Clayton, a Dr. Watson remarked on the fact that a permanent inflammable gas could be obtained by heating coal, and about the same time (1781) a patent was granted to Admiral Cochrane, Earl of Dundonald, for the extraction from pit coal, by heating or distillation, of tar, pitch, oils, volatile alkalies, mineral acids and salts. The Admiral worked his process at Culross Abbey. The gas was generally allowed to escape into the air, but occasionally quantities were collected in metal vessels for the edification of the learned Earl's friends. This patent did not mark the first effort to extract valuable products from coal, for furnaces for heating coal to obtain coke for use in ironworks were in use on the Continent twenty years before, but it was undoubtedly the first recognition of the value of the volatile products driven off from coal

by heating. Some ten years later, a Scotchman, William Murdoch, distilled coal in iron kettles, conducted the gas through iron pipes to burners in various parts of his house at Redruth in Cornwall, and burned it for illumination, thus making himself the first practical gas producer and consumer in history.

The coal deposits of the world, which the demands of our present social systems are reducing at the rate of some millions of tons a day, date back for the most part to an age of the world's history known to geologists as the Carboniferous. This period, which is generally placed some twenty million years ago, probably lasted about six million years. A very hot, damp climate favoured the growth of enormous forests of giant ferns and non-flowering plants, the leaves of which, under the tropical heat and light of the sun's rays, extracted from the carbon-dioxide of the air the carbon necessary for their growth. This six-million-years' accumulation we are now dissipating at a rate which will probably exhaust it in less than six hundred years, returning to the atmosphere by its combustion the carbon-dioxide from which it was formed some twenty million years ago. Thus one may say of coal that it came from gas, and to gas it will return, though a certain proportion of ashes is being produced in the process.

The deposits now being worked vary from the relatively younger and softer peat and lignite to the hard anthracite. The coal chiefly employed for domestic purposes, and for the preparation of gas, is the so-called bituminous or soft coal, of which the biggest proportion of the deposits of Britain consists. This coal, when heated in closed vessels or retorts, yields a very great variety of products—the coke, used chiefly for metallurgical purposes, remains behind in the retorts, the oils, ammonia and other compounds first sought

by Admiral Cochrane are separated by means of coolers and washers, whilst the gas is purified to free it from sulphur compounds before being pumped to the gas holders for use.

William Murdoch, the founder of the coal-gas industry, was, at the time of his discovery, in the employment of the firm of Boulton and Watt, of Soho Works, Birmingham. This firm was making the steam engines designed by James Watt, some of which had been ordered for use for driving pumps for the tin mines in Cornwall. Murdoch was sent to Cornwall to supervise the erection and working of these engines, and it was at Redruth that he began his work on coal gas in 1791. The new industry made but slow progress at first—it was not until 1802 that the first public demonstration of the new method of lighting was given, the Soho works of the firm at Birmingham being illuminated in that year to celebrate the peace of Amiens. As so often happens with great discoveries, an independent worker was approaching the same end as Murdoch at the same time. A Frenchman named Lebon had discovered as early as 1791 that illuminating gas could be obtained from wood, and stored indefinitely—he devised what was probably the first gas holder by inverting a small vat in a larger one filled with water. Lebon also obtained but little recognition—he did not obtain a patent until 1799. In 1800 he brought forward a proposal to light the streets of Paris by means of gas obtained from wood, and in 1803 he was granted a concession to work a pine forest near Havre, the tar obtained by his process being needed by the French Government for shipbuilding. In 1804 he was mysteriously assassinated in Paris.

A Moravian named Winser, who had seen in Paris some lamps in which Lebon's gas was burned, took a

share in the development of the industry at this point. He came to England, and formed a committee for lighting streets in London by gas, a step which resulted, after a practical demonstration in 1807, in which Pall Mall was illuminated by means of gas, in securing Parliamentary power to grant a charter in 1810. This led to the formation of the Chartered Gas Company, the parent of the Gas Light and Coke Company. The invention of the gas meter by Clegg in 1815 enabled the company to supply gas at a definite price to consumers, and by 1825 the new form of lighting was well established in London.

The burners originally used by Murdoch were of a very simple type—he merely welded up the end of his gas-pipe, and bored three small divergent holes. This original burner was known as the Cockspur, from the shape of the flame formed—it gave about 1 candle-power per cubic foot of gas burned per hour. This was the burner employed by Murdoch when fitting up the works of Phillips and Lee in Manchester in 1807 for illumination by gas. The first improvement on this was the flattening of the welded end of the pipe, the holes being bored in line in the flat end—this type was known as the Cockscomb. The next step was to make the holes continuous, that is, to make a thin line jet at the flattened end of the pipe—this gave the Batswing type familiar to the last generation. About 1820 a type known as the Union or Fishtail burner was devised by Neilson of Glasgow, who first made use of the hot-air blast in iron smelting furnaces. These later flat-flame burners gave up to 2½ candles per cu. ft. of gas burned per hour.

It was soon found that the end of the iron gas-pipe did not make a very suitable form of burner, and steatite, a soft silicate mineral, was introduced for the

tips of the burners. The next advance was the introduction of the Argand or ring burner, adapted from the circular wick oil lamp—as used for gas, this was merely a flat ring secured on to the end of the pipe, with numerous jets arranged in a circle round the ring. This brought the candle-power per cu. ft. up to about 3. In 1853 Frankland introduced his regenerative burner—this was an Argand burner fitted with a double chimney, the air to be consumed being drawn down between the two chimneys, and heated on its way by the hot gases from the flame which passed up the inner chimney. This preliminary heating very greatly improved the power of the flame, a candle-power of 10 units per cu. ft. of gas per hour being obtainable with burners of this type. Regenerative burners were also designed by Bowditch in 1854, and Siemens in 1879, but the degree of illumination which could be obtained in this way was limited by the extent to which the burner and fittings would withstand the high temperatures produced. Illumination by gas seemed to have reached its best results, and appeared to be seriously threatened by the development of the application of electricity to lighting, which began to be of practical importance about 1880. The gas companies turned their attention to the employment of gas for cooking and heating purposes, but the use of gas for lighting received a great impetus from the development of the incandescent mantle in the early nineties, and from that time the two systems—lighting by gas and by electricity—have advanced with almost equal strides.

(*e*) **Electricity Applied to Lighting.** The foundations of the study of electricity were laid in the second half of the eighteenth century, though it was not until the work of Faraday on induced currents, early in the nineteenth century, laid the way for the development

of the dynamo, that commercial generation and application of electricity became possible. The earliest form of electric light was the arc lamp, attributed to Davy about 1801. An arc is obtained when an electric current of suitable voltage and density is obliged continuously to bridge an air-gap in a circuit, and is generally produced by bringing together two rods of carbon attached respectively to the positive and negative terminals of a source of supply, and then separating them slightly. The arc may be obtained either by direct or alternating current supply, but the former is more efficient and gives a better distribution of the light. The positive carbon, which is the hotter, burns away very rapidly, and is therefore made bigger than the negative, but the rate of loss, which, in a 500-watt lamp is about 1 in. per hour, can be very greatly reduced by enclosing the arc, so as to reduce the quantity of air which gains access to it to a minimum. An enclosed lamp with a voltage of about 85, and a current of 10 amperes, will give a light of about 1,500 candle-power, but this can be considerably increased by using electrodes impregnated with salts of calcium, magnesium and similar metals ; these chemical or flaming arcs, as they are termed, cannot, however, be enclosed, so that the rate of loss of the electrodes is very high.

Arc lamps, from their high candle-power, big current consumption, and heavy initial and running costs, as well as from the amount of skilled attention they require, are not suitable for domestic lighting. They find their chief employment in shop and street lighting, in which field they bear the more recent competition of the high pressure incandescent gas lamps, and in projection lighting, as in searchlights, magic lanterns and cinematographs. For indoor lighting a simpler, cheaper

and more moderate-powered light was required, and the development of electricity in this field was inaugurated by the work of the American inventor, Edison. This type of lamp, the incandescent electric lamp, depends on the fact that when an electric current passes through a conductor of very high resistance, much heat is liberated, in the ideal case sufficient to raise the conductor to so high a temperature that a large proportion of the electric energy is transformed by the resistance into light energy, and radiated as such. The difficulty in designing such lamps has been to obtain a conductor which will withstand the high temperatures required. The early workers, about the middle of last century, endeavoured to use platinum, a metal which melts at a temperature of 1,775° C., equivalent to just over 3,400° F. This melting-point was too low, and the character of the filament too fragile for the purpose. In 1878 Edison was working with platinum covered with carbon, which has a very high radiating power, but eventually he abandoned the platinum, and concentrated his work on the endeavour to obtain filaments of sufficient strength from carbon only. Owing to the rapid burning away of the heated carbon, he found it necessary to mount his filament in lamps from which the air could be exhausted, and eventually Swan and Edison succeeded at the same time in evolving successful lamps on these lines.

The earlier filaments were obtained by charring some organic material, such as parchmented thread or bamboo, previously cut to the required shape, but these were not very satisfactory in use. Later it was found better to prepare strong threads of cellulose by forcing a solution of that material (generally in the form of purified cotton-waste) in zinc chloride and water through dies into a dry, hot atmosphere, which caused the water

to evaporate, and left a hard, strong thread. This thread was bent into the necessary shape, packed in powdered plumbago (a pure, soft form of carbon of natural occurrence) in a plumbago crucible, and strongly heated, the cellulose being thus destroyed, and a residue of carbon left, which preserved the original shape. This was then connected to platinum electrodes, and mounted in bulbs of lead glass ; this glass expands when heated to almost the same extent as platinum, so that there is no danger of breaking from heat when in use. The filament is then heated by the passage of the electric current, whilst a stream of coal gas or benzene vapour is passed through the lamp—this has the effect of depositing upon the filament a very dense hard skin of carbon from the gas or vapour. The bulb is now exhausted of air whilst the current passes, and sealed up ; it is then ready for use.

The temperature of the carbon filament lamp in use is about that of the melting-point of platinum, 1775° C., and at that temperature it consumes from 2½ to 3 watts per candle-power. Higher temperatures and greater efficiencies may be attained, but the life of the lamp is very much shortened, the carbon being volatilized or sublimed off from the filament, and forming a dark opaque deposit on the glass of the bulb. Hence research with this type of lamp has been directed to find some material for the filament which will resist higher temperatures, and satisfactorily conduct the current.

In the Nernst lamp, patented in 1897, the filament was formed of certain oxides, known as Rare Earth Oxides, which have the property of conducting the electric current to the required extent when very hot. The filament had to be raised to the required temperature by means of an auxiliary heater of platinum wire, which was automatically cut out when the filament

itself began to glow and conduct the current. The Nernst lamps gave a brilliant white light, and were fairly efficient, but they had the disadvantages of the time required to reach the required temperature, the great size of the lamps and fittings, and the complex cut-out arrangement ; further, they were not suitable for small power lights. For these reasons, they could not face the competition of the metal filament lamps, which came into the market in the early years of this century.

Many rare metals have been suggested from time to time for the preparation of filaments for lamps. Platinum was tried by many earlier workers ; osmium and zirconium, tantalum and tungsten have all been used, but only the last two have given really satisfactory results. All of these melt in the neighbourhood of 2,000° C., and the difficulty has been to prepare them pure in a coherent form, so that they could be drawn and worked into filaments. The first success was obtained by von Bolton in 1904, who obtained pure tantalum in a form which could be drawn, by melting the powdered metal in a vacuum, by means of the electric furnace. He found it to be harder than platinum, to have a greater tensile strength than steel, and to have a melting-point over 2,000° C., whilst its resistance to the electric current was satisfactory. From 2 ft. of wire only one five-hundredth of an inch in diameter, he obtained a filament suitable for a 25 candle-power lamp, requiring a current of 0·36 amperes at 110 volts, a consumption of only 1·6 watts per candle-power. The Osram lamp, of which the filament is made from an alloy of tantalum and tungsten, consumes about 1·5 watts per candle-power, whilst with a tungsten filament, the figure falls to 1·25 watts. The half-watt lamp, in which the bulb is not evacuated, but

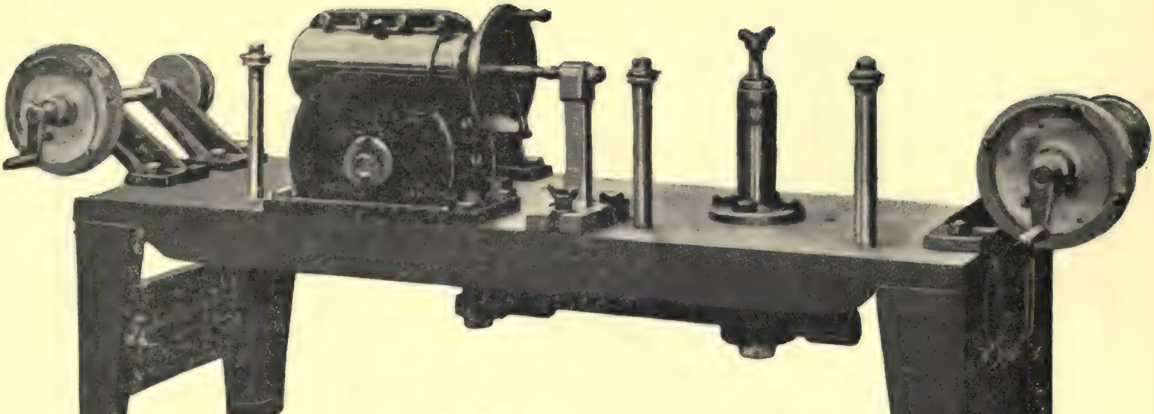


PLATE NO. 2

THE SPIRALIZING MACHINE

This machine winds the tungsten filament into a very close helix upon a mandrel of suitable diameter.

A drum carries the mandrel through a miniature lathe head on to a receiving drum.

The chuck carries the reel containing the Tungsten Wire. The machine is rotated with the mandrel moving slowly in one direction while the Tungsten Wire is wound round the mandrel.

The machine is so built that the number of turns per inch can be varied as required.

is filled with nitrogen or argon under pressure, reaches the wonderfully low consumption of 0·5 watts per candle-power—lamps of all powers can now be obtained with this high efficiency, but the initial cost is high, and the lamps are still somewhat fragile. The manufacture of the modern metal filament lamp involves a great deal of delicate and complicated manipulation, much of which is carried out with the aid of ingenious machinery. Plates 2, 3, and 4 show some of the machines employed for this purpose. The application of mechanical methods to these difficult operations calls for much ingenuity and patience, but results in products not only uniformly standardized to a high level, but very much cheaper than would otherwise be possible.

Another form of electric lamp is the vapour lamp, in which electric discharges pass through tubes containing mercury or cadmium, but from which all the air has been exhausted before sealing. The current is carried by the vapour of the metal, and high light intensities are obtained with very low current. The efficiency is about the same as that of the arc lamp, from one-fifth to one-third of a watt per candle-power. Metal vapour lamps, however, do not give white light, but only light of one particular shade, depending on the metal used—mercury gives a most tiring and unpleasant greenish light—so that they are used only in scientific work, or where some fantastic or arresting effect is sought. It may be possible, however, to obtain more pleasing and useful effects from this type, in which case the cheapness of prime and running costs, and the extraordinarily long life should make vapour lamps of great importance.

(f) **Some Other Lighting Agents.** Apart from the commoner methods of illumination which have been mentioned above, viz., oil lamps and candles, coal gas

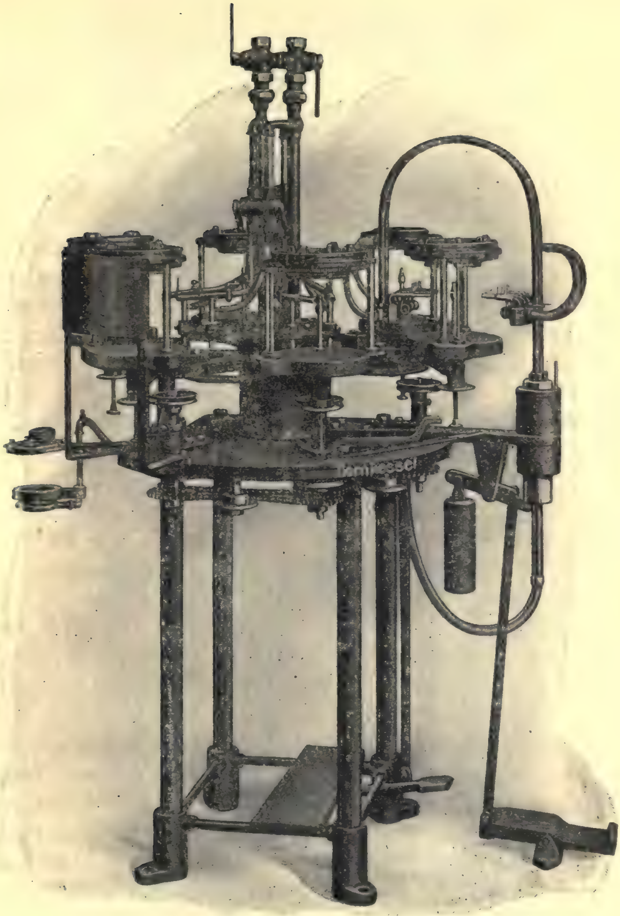


PLATE NO. 3

THE SEALING-IN MACHINE

On this machine the bulb is welded round the glass tube which holds the filament, and it is over this weld that the brass lamp cap is fitted. The machine consists of a number of rotating arms carrying the tubulated bulb and the filament. The " foot " carrying the mounted filament is placed on the spindle and over this a bulb is placed which rests in the bulb carrier. The complete unit is rotated and comes into contact, first, with a preliminary heating flame, and, finally, with the big sealing-in flame. These flames force the bulb neck until it and the flange of the foot meet and weld. A perfect and symmetrical shape is thus obtained.

and electric lighting, there are other minor or occasional methods, used for the most part on account of their suitability for some special purpose. One of the more important of these is acetylene lighting. Acetylene is very easily prepared as required by the action of water on calcium carbide, and when lighted in suitable burners gives a most intense white light. The calcium carbide is produced by the action of coke on lime, at very high temperatures, and is also obtained as a by-product in the manufacture of phosphorus by the action of coke on calcium phosphate in the electric furnace. It is an exceedingly hard, granular, greyish substance, usually put on the market in small lumps contained in sealed or airtight tins. Owing to the ease with which it reacts with water, forming acetylene, it is dangerous except when handled with proper precautions, and for this reason there are stringent regulations governing its transport and storage.

Acetylene lighting is especially suitable for cycle and motor-cycle lamps, and for vehicles of all kinds which do not generate or carry electricity. It is also valuable for domestic lighting where gas or electricity is not available. The generator and burner are usually combined in one apparatus, so that the lamps are very little more complex than an ordinary oil lamp, and the gas is so easily generated as required that there is no need to make it separately and store it. This would indeed be dangerous, as the gas acts on metals, forming compounds liable to explode. As normally handled, it is quite safe, and the objections to its use seem to be mainly concerned with the precautions necessary in handling and storing the carbide.

A form of lighting sometimes adopted before coal gas and electricity came into wide general use was that obtained from the so-called air-gas. This was a mixture

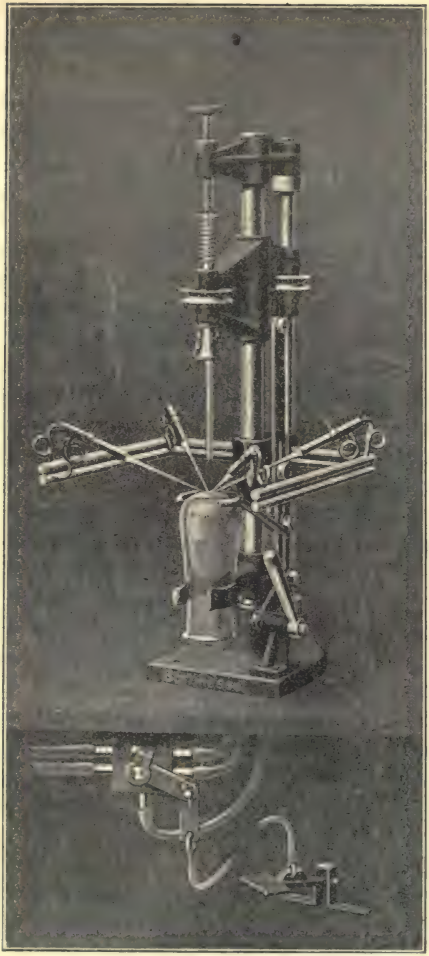


PLATE No. 4

THE TUBULATING MACHINE

This machine fixes a tube on the bulb end, through which the air is afterwards drawn in the operation of exhausting. First a hole is blown into the bottom of the bulb. The bulb is then placed in the ring of gas flames, above which the piece of glass tube is carried, and, when the bulb and the glass tube are sufficiently hot to be welded together, then, by means of a treadle, the glass tube is brought down to the bulb and thus makes the join.

of air with some combustible vapour, obtained by passing air through or over some volatile liquid such as petrol, or the light oil from coal tar. As may easily be imagined, the light obtained from such a mixture was very variable, depending largely on such irregular factors as the temperature and dryness of the air, the surface of liquid exposed, rate of the air current, and so on. Recently such methods have been revived to suit incandescent lighting, as the composition of the mixture of vapour and air can be adjusted by suitable controls to give the almost invisible high temperature flame required for the mantle. The device used, known on the Continent as the Aerogene, consists of a revolving coil dipping into petrol contained in a cylinder through which air is passed at a pressure of from 6 to 8 in. of water column. The air-vapour mixture, with a suitable incandescent mantle, will give an illumination of 30 candle-power per cubic foot of gas per hour.

Natural gas has, of course, been used on a large scale for heating and lighting, but the supplies are variable and uncertain. Such gas generally occurs in coal or oil-bearing neighbourhoods, but quantities sufficient to repay the cost of laying pipes and mains to conduct it to towns in the district are seldom met with. The great accumulations in the Pennsylvania coal and oil fields, which were used for lighting Pittsburgh, were consumed in ten years. In Western Ontario also great quantities have been found, and many towns in the province draw their gas from this source, but it is believed to be diminishing, and may give out at any time.

Another form of illuminating gas which has achieved success for certain purposes is Oil-gas, made from the petroleum distillate between ordinary lamp oil and the lubricating oils. These fractions, which have no great

value for other purposes, give a very rich permanent gas by suitable treatment. The oil is allowed to drop slowly into a vessel heated to a high temperature, and on coming into contact with the hot sides or floor is suddenly decomposed, giving practically only permanent gas. This method of manufacture appears to have been first used by Pintsch, and the gas obtained is often called Pintsch's gas. The gas can be compressed into cylinders or reservoirs without danger, and in this form is carried on railway trains, lightships, etc., for lighting either in the old flat-flame burners or with incandescent mantles. Oil gas is used in lighthouses, generally on the incandescent system, and in buoys and unattended coast lights, as it can safely be stored under pressure sufficient to give three or four months' supply. It is also made on the spot for use in isolated houses and factories, but for use in this way, gasholders are generally required.

Oil gas is very generally used also for enriching water gas, which is a mixture of carbon monoxide and hydrogen obtained by passing air and steam alternately through glowing coke. Water gas burns with a colourless invisible flame, and to increase its illuminating and heating power, it is frequently mixed with oil gas. The mixture can be made as suitable for heating and lighting as coal gas, and is very generally prepared and sold by gas companies without any distinction.

One other illuminating device remains to be mentioned before the detailed discussion of incandescent mantles is taken up. This is the limelight, which seems to have been introduced independently by Drummond in England, and Hare in America, in the twenties of last century. This light, which was very largely employed for projection purposes during the second half of the century, was obtained by heating a pencil

of lime or magnesia, sometimes mixed or coated with zirconia, in the oxy-hydrogen flame. In 1867, the Place de Tuileries, and the Hotel de Ville in Paris, were illuminated by somewhat similar lights, obtained by heating rods of zirconia in flames fed with oil vapour and oxygen. A very similar device of more recent times is the Bleriot lamp, used for automobile head-lights, in which zirconia is heated in the same way by means of mixed oxygen and oil vapour flames.

CHAPTER II

INCANDESCENT LIGHTING

(*a*) **Definition and Limitation of Term.** Though the term Incandescent Lighting is generally restricted to the form of lighting in which a mantle of highly resisting material is heated to incandescence by means of mixed gas or vapour-air flame, it has long been known that such a restriction of the definition is illogical. Properly speaking, practically every light in common use is an incandescent light, that is, every light is produced by raising some solid to the temperature at which it becomes incandescent, or gives out light radiations. When a solid is heated, the motion of its molecules, or constituent particles, is increased, and the higher becomes its temperature, the greater becomes the kinetic energy, or energy of motion, of the molecules. This motion of the molecules sets up wave motions in the ether, which travel outwards in circles from the point of disturbance until they are arrested and either reflected or absorbed by some material substance. At lower temperatures these wave motions or radiations set up heat when arrested. As the radiating substance becomes hotter, the waves it sends out begin to cause more and more the effect of light when arrested. Thus to obtain the radiations we know as light, it is necessary to raise some body to the temperature at which it gives out the maximum of light waves as against heat waves, which, in practice, is the highest possible temperature we can obtain. Even with the electric arc, which gives almost the highest temperature we can obtain, the radiations given out contain only between 10 and 15 per cent of

luminous rays ; with the carbon filament lamp, only 5 per cent, and with an ordinary oil lamp only 3 per cent of the total radiations are light radiations. Hence the object of all lighting systems must be, firstly, to obtain the highest possible temperature, and secondly, to obtain some solid substance which will resist that temperature and possess the highest possible light-radiating power at that temperature.

In the wood and coal fire, in the candle, the oil lamp, and the flat flame of the coal gas burner, as well as in the acetylene flame, the solid particles which give rise to the light radiations are all the same—all carbon. In all these cases, the materials burned consist of compounds of carbon, and the flame consists of several zones or regions of different combustion and light-giving effect, one inside the other. In the innermost zone, which is almost invisible and gives out practically no light, the effect is chiefly one of high temperature, very little air being present to effect combustion ; in this zone the gas or vapour is decomposed, some hydrogen being converted to water by the small amount of air present, whilst compounds much richer in carbon, together with free carbon itself, produced from the gases by removal of the hydrogen, pass outward to the second or middle zone. Here the proportion of air, though greater than in the first zone, is still insufficient for complete combustion ; in this zone the particles of free carbon are heated by the partial combustion of the gases and are raised to the temperature of incandescence. The degree of incandescence obtained in this zone depends on the composition of the gas or vapour used, which largely determines the amount of free carbon available to be brought to incandescence, and on the temperature obtained, which depends on the design of the burner, the temperature and proportion

of oxygen in the air supply, and so on. Finally, in the outer zone the partially burned gases meet an excess of air, and the combustion is complete—in this zone there is no free carbon, and the flame is therefore again non-luminous.

Where electricity is used for illumination, the heat required to raise the temperature of the radiating solid is obtained without combustion by causing the current to overcome a very great resistance, which, in the case of the arc lamp, is an air-gap, and in the case of the filament lamp is the filament itself. It is possible, however, to obtain luminous radiations from the electric current in a rather different way, without reaching the high temperature necessary to raise solids to incandescence—the metal vapour lamp and the Crooke's vacuum bulb are examples of this method—but the lights obtained consist of radiations corresponding to particular parts of the spectrum only, and so are not suitable for general illumination, which requires radiations corresponding to all or nearly all of the visible spectrum.

It is evident, therefore, that all forms of illumination in general use are incandescence lightings, and that the incandescence is obtained by heating some suitable solid, whether by combustion or by means of the electric current. In the form of lighting generally known as incandescent lighting, however, the illumination is obtained by raising to incandescence, by means of the non-luminous combustion of gases or vapours, a device known as a mantle, which consists of a very fine network of highly resisting oxides, supported in the flame. The non-luminous flame is obtained by mixing the gas or vapour with air or oxygen before it reaches the burner, so that the flame is not divided into zones as in the ordinary batswing or lamp flame,

but is uniform and very hot throughout. The mixture of sufficient air or oxygen for combustion is very important; if there is not enough oxygen in the mixture before burning, the flame will contain at one point or another free carbon, which is deposited on the mantle and reduces its radiating, i.e. light-giving, power enormously. This constitutes the great difficulty in the effective use of oil for incandescent mantle lighting —oil vapour is so rich in carbon as compared with coal gas that effective admixture of the large quantities of air required for complete combustion is in practice very difficult.

The introduction of the Bunsen burner in 1855, simple though it appears now, was the first attempt to obtain a non-luminous flame from coal gas. Before that time, the only non-luminous flames available in practice were those of water-gas burners, spirit lamps and the oxy-hydrogen blowpipe. The Bunsen burner consists simply of a vertical tube, at the lower end of which gas is admitted from a small jet placed centrally in the tube; air is drawn in from apertures in the side of the tube just above the jet, and mixes with the gas as it ascends, the mixture being ignited as it issues from the top of the tube.

(*b*) **Early Attempts at Incandescent Lighting.** During the earlier years of the nineteenth century, several different chemists observed that many metallic oxides, i.e. compounds of metals with oxygen, became incandescent when heated in the non-luminous flame, emitting a bright white light. An interesting case is that of thoria, the oxide of the metal thorium, which constitutes 99 per cent by weight of the modern gas mantle; the incandescence of this oxide when heated was observed as long ago as 1825 by the great Swedish chemist, Berzelius.

The first practical employment of this property of the oxides was in the limelight, which was proposed by Hare in Pennsylvania in 1823, and by Drummond in England in 1826. The limelight, however, is suitable for very restricted use only, and its employment did nothing directly to assist domestic lighting. About 1839 a very interesting forerunner of the modern mantle was proposed by Cruickshank ; his device was made of platinum wire, covered with such oxides as lime and thoria, and was heated by means of water gas, the only hot non-luminous flame available, except the oxy-hydrogen blowpipe. In 1846 mantles of platinum wire alone were employed by Gillard, the flame of burning hydrogen being used ; the hydrogen was obtained by passing steam over heated iron. In 1848 these lamps were employed at Paris and Philadelphia, and some time later at Narbonne, where the system was in use for nine years ; in these cases water gas was used instead of hydrogen. This work of Gillard is highly interesting, in that what we now call incandescent lighting was shown to be a practicable system, which could be kept in operation for months and years. The high price of platinum and the fact that the mantles had to be renewed every few months, however, prevented the system from becoming a permanent success.

The attempt was renewed again in 1882 by Lewis, the ordinary Bunsen burner flame fed with coal gas and air being substituted for the water-gas flame. In the same year, lamps in which a platinum mantle was heated to incandescence in a flame of coal gas mixed with hot air were exhibited by Popp at the Crystal Palace. These lamps failed from the same difficulties as Gillard had encountered. Platinum, from its great resistance to heat and chemical agents, thus received a great deal of attention from the earlier workers both

in electric and gas incandescent lighting, but was finally abandoned in both systems.

The light-emitting power of heated metallic oxides was employed again by Frankenstein in 1849. He endeavoured to increase or "multiply" the light of a gas flame by means of a mantle obtained by impregnating gauze with a paste of chalk and magnesia ground up with water. This attempt might almost have served as a model for the subsequent work of Welsbach; it failed from the great fragility of the mantle. Welsbach's work was certainly not based on Frankenstein's, as it arose from a purely chemical investigation, but such instances of later and successful duplication of earlier unfruitful attempts are not uncommon. A somewhat similar case in the same field is the attempt of Edison in 1878 to employ a mantle of platinum wire covered with zirconia and oxides of the rare earth metals, which practically duplicated the attempt made by Cruickshank in 1839. A somewhat similar device was employed in 1880 by Clamond, who made a mantle of magnesia, which he supported in a platinum cage and heated in a flame of coal gas and hot air. His mantle was made by grinding up powdered magnesia into a paste with water containing magnesium acetate, and by forcing this through a die to obtain a ribbon, which he wound crosswise on a wooden shaper. This mantle was carefully dried, and then heated to decompose the magnesium acetate to magnesia. This gave a very bright light, but was too fragile for common use.

In 1883 a comb of magnesia with lime or zirconia was produced by Fahnehjelm in Stockholm. The comb was formed of rods and plates of the oxides, and was suspended over the burner, giving a cheap and fairly efficient device with a fairly long life. It came

into competition almost at once, however, with the Welsbach mantle, and soon dropped out.

(*c*) **The Work of von Welsbach.** Dr. Carl Auer, Baron von Welsbach, to whom probably the coal gas industry owes more than to any other man of his generation, began his work on the rare earth elements about 1880. Auer was first and foremost a scientist, and his chemical researches were undertaken without any idea of commercial application. He chose for his subject a group of substances of which very little was known with certainty, which were thought to be extremely rare, and to occur only in few places and in very small quantities, and which certainly would have been described by the very few people of that time who had any knowledge of them as of almost ultra-academic interest. Within the forty years which have elapsed since the commencement of his work, these substances have been found in every part of the world and in many deposits of enormous extent, so that the name Rare Earths, which forty years ago appeared entirely appropriate, is to-day devoid of significance. The ultra-academic interest has developed into a commercial importance of considerable magnitude; the mining and treatment of monazite sands, the preparation from the monazite of the nitrates of thorium and cerium, and the manufacture of mantles are all industries which have developed within the last thirty years directly from his work, whilst the incandescent mantle has assisted to an enormous extent the expansion of the coal gas industry, and through that the manufacture of coal-tar dyes, of perfumes, synthetic drugs and photographic chemicals, and of fertilizers. The practical application of this single observation made in the course of a purely scientific research is indeed one of the romances of modern industry, and serves as a

wonderful example of the extent to which science may benefit the world. Some millions of separate and distinct substances are known to chemists, of which but a few hundreds are employed to any extent—of the majority of the remainder, probably only an ounce or two has ever been made, and a few lines in some scientific journal summarizes our knowledge of each of them; yet many of them may in the future affect in some degree our whole civilization. Mustard gas was first made some fifty years ago by an Englishman named Guthrie, in the course again of a purely academic research; recently it was a powerful and malignant weapon, used with fearful effect probably on tens of thousands in the combatant armies. Chemicals as yet unknown will be used on a far more fearful scale should another war occur to shake the painful progress of centuries into ruins. Unimaginable possibilities are latent in the realms both of pure and applied research, and a growing realization of this, a slowly growing realization, unfortunately, is gradually changing all our social conditions.

The rare earths form a group of substances so closely related to one another that the separation of individual members is a most tedious and lengthy task, whilst their chemical and physical properties are so much alike that there is practically only one method available for recognizing them individually. This method was first employed about the middle of last century by the German scientist, Bunsen, the inventor of the burner which bears his name, and is based on the fact that every chemical element may be made to emit special radiations peculiar to itself. Ordinary white light is not a pure light, but consists of a very great number of different lights or radiations, corresponding to the various colours. These different lights have different

wave lengths, that is, the waves to which they give rise in the ether, and by means of which light and heat and electric energy travel through space, have different dimensions. Thus, heat waves, which are emitted by glowing fires, by the sun, and by all hot bodies, and which give rise, when arrested by matter, to the sensation or effect of heat, have big wave lengths ; the light rays have shorter wave lengths, red light having the longest and violet the shortest, whilst actinic rays, the rays which have the greatest effect in photography and in chemical action, have still shorter wave lengths. In dealing with the various kinds of light, wave length is employed to characterize them, and to refer to them, and the wave lengths of the special lights emitted by each element afford a very delicate and certain method of detection and identification.

If sunlight be caused to pass through a prism made of some transparent substance, it is deflected from its path, the different lights of which it is composed being deflected to different extents. Thus, if a single beam of sunlight be caused to fall on a prism by means of a slit in a shutter in a darkened room, it will be found after passing through the prism to have broadened out in a coloured band, the orders of the colours forming this spectrum, as it is called, being red, orange, yellow, green, blue, violet and indigo. These colours are seen in the same order in the rainbow, being produced by the deflection of the rays of the sun passing through the spherical drops of water falling through the air. The colours are not in sharply-defined bands, but pass into one another by gradual change from one end to the other of the spectrum. They consist in fact not of seven, but of several thousand different colours ; sunlight really consists of several thousand lights, each having its own wave length. The wave lengths

corresponding to the various positions in the spectrum are known, and it is sufficient, in determining the wave length of any given light, to find its place in the spectrum, which is generally done by photographing it on to a plate on which the standard spectrum has already been mapped out.

The method of identifying substances by means of the lights characteristic of their elements is called Spectrum Analysis, and of the several variations of this that may be used the method of the arc spectrum is generally employed. In this method, the electric arc is formed between carbon electrodes, one of which has either been saturated with a solution of the substance to be examined, or has been made hollow and filled up with the substance in paste or powder form. The light produced by the arc is caused to pass through a fine aperture, and allowed to fall on a prism or a diffraction grating, which broadens out the spectrum to any desired extent. The light from the prism or grating then passes through appropriate lenses on to a photographic plate, on which a standard spectrum has already been marked out, so that the two lie side by side on the plate, which, after development, is examined to identify the light emitted by the arc, and so to discover the elements present in the substance under examination.

The apparatus required for such work is complicated and expensive, and the determinations require much time and skill. For the numerous observations necessary in the course of an endeavour to separate or isolate any particular member of the rare earths, simpler methods may be adopted to give rough ideas before the elaborate analysis is made. Von Welsbach was engaged on an examination of some rare earth substances, at that time thought to be simple and

homogeneous, but which he believed to be mixtures, and which he later succeeded in showing to be mixtures of new substances not previously known. In the course of his work, he found it necessary to make a great number of rough spectrum examinations, and for this purpose heated in the Bunsen flame platinum wires previously dipped in the solutions to be examined. The light obtained in this way was not permanent or bright enough for his purpose, and in seeking another method he found that if a strip of cotton be dipped into a solution of rare earth compounds, and after drying be suspended in a Bunsen flame, the cotton is burned away, and the oxides of the rare earths are left behind in the form of a skeleton of the cotton thread, keeping its exact shape, and remaining coherent, instead of falling to powder.

This skeleton thread of the oxides, if left in the flame, glows brilliantly, and emits light which can be examined for a rough spectrum test to give an indication of the elements present. Von Welsbach perceived the importance of this glowing skeleton of oxides, and following up the idea to which it gave rise, he immersed whole strips of cotton fabric in his solutions, and found that after drying and burning off the cotton, he obtained strong coherent skeletons of glowing oxides, in the exact form of the fabric employed. From this it was but a short step to the preparation in the same manner of mantles which could be permanently suspended in the Bunsen flame, which by their intense glowing gave an illumination strong enough for domestic purposes. As by this time—about 1883—coal gas was in very general use, and as the Bunsen burner is of extreme simplicity, and readily fitted to any gas supply, everything was favourable for the immediate development of his discovery, and the Welsbach mantle was accordingly

patented in the countries of Western Europe during 1884 and 1885.

In the early mantles, no very great care was employed in the selection of the rare earth compounds used, especially as the separation was so difficult. The light obtained varied in colour, green, yellow and orange tints being given by slightly different mixtures of the oxides in the mantles, and the illuminating power was about 8 to 10 candles per cubic foot of gas per hour. This was not sufficient to give the new method of lighting any very great superiority over the electric carbon filament lamps at that time becoming popular, and for some years the success of the incandescent mantle remained doubtful. Many different mixtures of rare earth compounds were tried by von Welsbach and his assistants, but none showed any great advance. About 1891, whilst examining the illuminating power of the oxide thoria, it was found that the intensity of the light given by the mantle became less and less as the thorium compounds used were made purer and purer. An examination of the impurity present in the thoria used showed it to consist chiefly of the oxide ceria. Pursuing this line, Auer tried the effect of adding the oxide ceria in gradually increasing quantities to pure thoria, examining the illuminating power after each addition. He found that whereas pure thoria and pure ceria have both relatively small illuminating power, mixtures consisting mainly of thoria, with very small quantities of ceria, have very high illuminating power. The light emitted by thoria increases enormously as ceria is added, reaching a maximum when the mixture contains nine parts of ceria per thousand, and diminishing again very rapidly as this proportion is increased. Von Welsbach announced his result by patent in 1893, and from that time the "Auer Mixture,"

as it is called, containing 99·1 per cent of thoria and 0·9 per cent of ceria, has remained beyond doubt the best. The illuminating power of the mantles made from this mixture was nearly double that of the earlier mantles, the ordinary upright form giving from 15 to 18 candles per cu. ft. of gas per hour.

(*d*) **Developments of Auer's Work.** Naturally, the inauguration of so important an advance in the art of illumination gave rise to many attempts to evade the Auer patents, which covered the use of practically every known or possible kind of fabric and compound of the rare earths. Several of these attempts were quite legitimate: the Sunlight mantle, for example, was made from the oxides of aluminium, chromium and zirconium, materials not covered by Auer's patents. This mantle gave a light of from 12 to 15 candles per cu. ft. of gas, but its life was very short and the light diminished in use very rapidly. Mixtures of aluminium and uranium oxides have also been patented and mantles have been made from thoria alone and afterwards dipped in a collodion solution containing cerium compounds; but in no case have results equal to those obtained by von Welsbach been secured.

Less scrupulous were the methods in which thorium and cerium compounds were employed under names intended to give rise to the impression that they were new and different substances. Owing to the great difficulty of investigating the rare earth elements, and the uncertainty prevailing at that time with regard to the number of elements in the group, dishonest people thought it possible to infringe Auer's patents by claiming to have discovered new elements of the group which could be employed for the manufacture of mantles, and such names as Russium, Lucium, Cosmium and Neo-Cosmium were employed to cover what were in reality

various mixtures of thorium and cerium alone or with other substances. One enterprising firm went so far as to have an entirely fabricated account of the discovery and properties of a new element, for which the name Lucium was proposed, inserted in a well-known scientific periodical, and proceeded to manufacture mantles from thorium and cerium compounds under the impudent assertion that they were made from salts of this new element Lucium. All these attempts, however, served only to show how complete and far-reaching were the Auer patents, and to provide evidence of the value and importance of the new method of illumination.

Although the introduction of the thoria-ceria mixture enabled the Welsbach mantles to compete very favourably with the carbon filament lamp, the mantles themselves still left a great deal to be desired. Their chief defect was that, after being in use for some time, they were found to shrink considerably, and to lose much of their strength and light-giving power. Many methods were patented for preventing this depreciation. Many such patents suggested different methods of weaving the fibre of the cotton, or of thickening the threads at various points, and even the employment of metallic filaments in the fabric. The employment of silica or other oxides, worked into the fabric, or deposited on the mantle in some way, has been protected by several patents. None of these proposals has been found satisfactory. Much more important results have, however, been obtained by employing fabrics other than cotton, the structure of which is chiefly responsible for the depreciation of the mantles in use.

Cotton thread is spun from a very large number of short fibres, twisted together, and as the mantle of oxides left after burning off the cotton reproduces

exactly the original structure of the fabric, it follows that the oxide skeleton also consists of a large number of short twisted lengths. It is the natural effort of these short threads to untwist themselves which causes the mantle gradually to shrink and crumple up, thus withdrawing itself from the hottest part of the flame, which reduces the intensity of the light, and at the same time renders the structure as a whole much more fragile and more sensitive to shock and vibration. Greater care in selecting the cotton fibre used has materially improved the mantle from this point of view, and mantles made from cotton to-day yield more satisfactory service, but greater improvements have been made by selecting other fabrics, the best results having been obtained with ramie, first employed by Buhlmann in 1898, and with artificial silk, first used successfully by Plaisetty in 1902 to 1903.

Ramie, which is also known as China-grass or grass-cloth, is a fabric made from the fibres of the Tschuma plant, which grows in various parts of Asia, but most freely in the valley of the Yangtse-kiang river. The stem of the plant consists of extremely long and strong fibres, matted together by a resinous mixture, which is removed from the cut and dried stems by boiling them with caustic soda. The purified fibres, being so long, are easily woven into fabric in which the individual strands are not twisted to the same extent as in cotton, and mantles made from ramie fabric show in consequence much greater resistance to shock and vibration, and have much less tendency to contract, than those made from cotton. Mantles made from ramie are therefore used where strength is of importance, as, for example, in the lighting of railway carriages, where the vibration is very great.

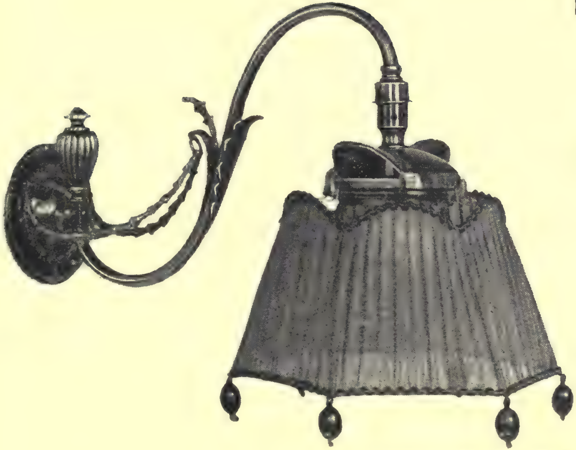
Artificial silk is an ideal fabric for the manufacture

Plate No. 5

A SHOWROOM OF THE SOUTH METROPOLITAN GAS COMPANY

Illustrating the modern applications of Gas to Lighting, Heating, Power, and various Domestic Purposes

of mantles, especially in cases where great strength and long life are important, as, for example, in street lighting by means of the high pressure incandescent system. This material owes both its lustre and the strength of the mantles made from it to the fact that the fibres of which it is built up are continuous, so that there is practically no twist introduced in the spinning. Artificial silk is made from cotton or from cellulose in any sufficiently pure form, by dissolving the material in some liquid from which it can easily be separated, either by chemical means, or by warming the solution to drive off the solvent employed. Generally the cellulose is treated chemically to transform it into some derivative easily soluble in a suitable liquid, and the solution is then forced under pressure through very tiny jets into a chamber hot enough to drive off the solvent, or into a bath in which the cellulose is separated again from the solution. In this manner it is obtained in the form of fine threads, which are wound on to bobbins as fast as the solution is forced through the jets, so that an absolutely uniform and continuous fibre is obtained. This fibre is extraordinarily light—a thread of 20 strands weighing 1 lb. would be more than 20 miles in length. Artificial silk was originally prepared by Chardonnet in 1890, to compete with natural silk as a fabric, in view of the high price of the latter. It has not, in fact, displaced natural silk to any extent, but its wonderful lustre, and the ease with which it takes fast dyes of all shades and colours, have obtained for it a market of its own, so that to-day several processes for making it are in use, and many thousands of tons are manufactured each year. The quantities consumed for the manufacture of incandescent mantles are relatively small, but the material is of great value to the mantle industry from its special suitability



South Metropolitan Gas Works

PLATE NO. 6

SHADE AND FITTINGS

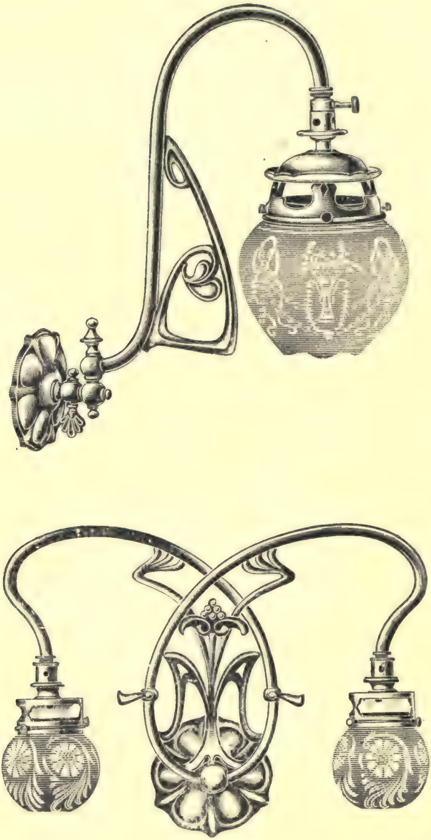
FOR STANDARD INVERTED BURNER

for the manufacture of very large and strong mantles.

In addition to modifications of the fabric from which mantles are made, important developments have taken place in the form of the lamps used, and in the method of supplying gas to the burners. The first really important innovation in the form of the lamps used was the introduction of the "Inverted" system about 1900, which greatly increased the popularity of incandescent lighting on account of the excellent light distribution obtainable. In the Lucas lamp, the inverted burner is used, and the air supply is greatly improved by modifications of the burner and chimney, whilst in the Scott-Snell system, the gas is delivered to the burner under pressure obtained by the motion of a plunger operated by the hot waste gases ; both these systems are much in use for shop lighting, and for outdoor lighting in towns, whilst the ordinary inverted system is employed to a large extent for the lighting of minor streets.

Plate No. 5 illustrates various forms in which inverted and upright mantles are employed for lamps of moderate power for internal and external illumination, and Plates 6 and 7 show a few of the very varied patterns of lamps and fittings now used freely for inverted mantles. Special types of lamps are also available for use in big public buildings, where ventilation has also to be considered. Plate No. 8 shows one of these, designed to be suspended high up, the air inlet and exhaust being arranged to promote currents upwards, and so to assist in that movement of air which is now known to be so important a feature of good ventilation.

Another important development was the introduction of the high-pressure system, in which the gas is delivered to the burners under increased pressure



Carpenters

PLATE NO. 7

TYPES OF FITTINGS FOR INVERTED MANTLES

through special mains. Big inverted mantles, usually made from an artificial silk fabric, are employed with this system, and mantles capable of developing 500 candle-power each are in general use. For major

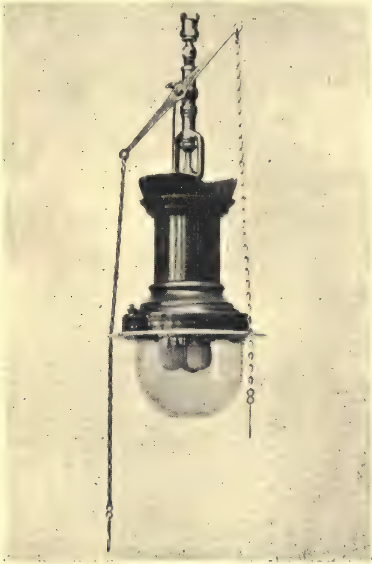


PLATE No. 8

LARGE INCANDESCENT LAMP

Designed for Illuminating and Ventilating Large Buildings, such as public halls, schools, churches, etc.

street lighting in big towns, this system has often been employed, lamps containing three big mantles, together developing 1,500 candle-power, being favourite units. With these big units, gas incandescent lighting has been able to enter into competition with arc lighting. The

use of the high-pressure system permits of the attainment of about 30 candle-power per cubic foot of gas per hour, as against 2½ candle-power per cubic foot with the old flat-flame burners.

Probably the most effective applications of the high-pressure system are to be found in London. The all-night activity of the newspaper world of Fleet Street is conducted with the efficient aid of this system, and the illustration (Plate No. 9) shows the remarkably fine distribution of light which is obtained. Plate No. 10 shows the same system as recently installed in Victoria Station, where it was found that the replacement of electric lighting by high-pressure incandescent gas lighting led not only to more effective illumination, but to a considerable reduction in cost.

Another important development in connection with incandescent lighting has been the introduction of automatic ignition devices. Whilst many attempts have been made to utilize the pyrophoric alloys which have attained some popularity in cigarette and cigar lighters, the only reliable system at present is the by-pass system, in which a tiny jet allowed to burn continuously within the lamp is momentarily enlarged when the main supply is turned on, and ignites the gas issuing from the main burner. This method is very reliable, and is largely employed for street lighting, and for big lamps used for outside lighting in towns.

The great value of incandescent mantles for increasing the illuminating power of flames has stimulated a great number of attempts to utilize this method in oil lamps, and though complete success has not yet been attained, some fairly reliable lamps are now available, and in lighthouses particularly the oil incandescent system is of very great value. The great difficulty with ordinary mineral lighting oils lies in the very high proportion

Plate No. 9

FLEET STREET AT NIGHT

This important thoroughfare, where night activity is almost continuous, is illuminated by Suspended High-pressure Incandescent Lamps. It affords a fine example of effective distribution of light

of carbon they contain, and the necessity of getting sufficient air mixed with the vapour to combine with all this carbon even in the inner zones of the flame. Enough air can be mixed without difficulty to give a non-luminous flame, but if a mantle be introduced into such a flame, carbon is quickly deposited upon it, and enormously diminishes its light-emitting power. In the form of oil incandescent lamp first introduced by the Welsbach Company, a burner carrying the mantle was placed a short distance above a circular wick, which sucked up the oil and so allowed it to vaporize before entering the flame. Air was drawn in through a tube passing inside the circular wick, as well as from outside the flame, but the results were not very satisfactory. In other patterns of lamp, air is pumped into the oil chamber, and escapes with the oil to the burner, passing on the way through tubes heated by the waste gases from the flame, in which the oil is vaporized, more air being sucked in at the burner. In the Altmann lamp, water is boiled in a separate chamber by means of a small auxiliary ordinary oil burner, the steam being used to inject the main oil supply into the main burner chamber, in the form of a fine spray, which is mixed with air drawn in by the injection effect as the vapour passes to the burner. The air pump method appears the most promising, as by this means between 3,000 and 4,000 candle hours can be obtained from a gallon of oil, against about 1,200 in the best type of ordinary wick lamp, an increase of about 300 per cent.

The first application of this system to lighthouses was made in 1898 at L'Ile Penfret light. Air is stored in receivers at a pressure of 125 lb. to the sq. in., which is reduced by means of a special valve to 60 lb. for use in the burner. At the latter pressure, it forces the oil in the form of a fine spray into a vaporizer chamber,

Plate No. 10

VICTORIA STATION

Illuminated by the High-pressure Incandescent System

whence the mixture passes to the burners. The cheapness and efficiency of this system led to its introduction into England in 1902. Three 50 mm. mantles burning only 3 pints of oil per hour, yield a light of 3,300 candle-power. Lightships are employed by the French Admiralty on this system with illuminations of 35,000 candle-power and upwards.

Oil gas has also been employed on a large scale for incandescent lighting, chiefly because of the fact that it can be highly compressed with safety, so that relatively large quantities can be stored in small containers. For railway carriage lighting, this system has been largely employed, but it is not now viewed with favour, on account of the danger of fire in cases of accident. The compressed oil gas is carried in cylinders under each carriage, and is burned in inverted burners carrying mantles made usually from ramie fibre, or from very long staple cotton, to give the necessary strength and resistance to vibration.

CHAPTER III

THE RARE EARTH INDUSTRY

(*a*) **The Occurrence of Monazite.** The first incandescent mantles, as already described in Chapter II, were made from various rare earth oxides, chiefly those of the elements lanthanum and zirconium. This first commercial utilization of these substances naturally led to a considerable demand for them, and therefore to the minerals in which they occur. These minerals were believed at that time to exist only in various detached localities in Scandinavia, chiefly in quarries scattered amongst the islands and fiords of the rocky and inaccessible coast. As Welsbach's work developed, and thoria was finally selected as the oxide from which mantles were to be made, a sort of fever broke out in Scandinavia, culminating in the wildest speculation in the thorium minerals. The best known source of thorium was then the mineral thorite, which had been discovered by Esmark in 1828, and analysed by the great Swedish chemist, Berzelius, who named it after the god of Scandinavian mythology, and discovered in it the new element which he called thorium in 1829. It is a relatively simple mineral, chemically speaking, being a compound of the oxides thoria and silica. Prior to Auer's work, the mineral had some value, owing to the fact that some varieties, which have a very clear and beautiful orange colour and well-formed crystal faces, were employed in jewellery. The commoner varieties, however, were practically worthless. When the " thorite-fever " was at its height, as much as £13 10s. per lb. avoirdupois was paid for the mineral,

but this speculative price soon sank again, the ordinary price given for manufacturing purposes being about £1 15s.

The great value of thorium minerals naturally stimulated a search for commoner and cheaper sources of the element, and it was soon found that one at least of the rare earth minerals was very widely distributed in Nature. This was the mineral monazite, formerly called also phosphocerite, from the fact that it consists chiefly of the phosphates of the cerium group of the rare earth elements. It was first described under the name Turnerite by the French mineralogist, Lévy, in 1823. Lévy obtained his specimen from the collection of an English chemist, Turner, after whom he named it. The name Monazite, from the Greek *μονάζειν*, "To be solitary," was first used by Breithaupt, who so named a mineral which had been found at Miask, in the Ural Mountains, by Menge in 1826. This mineral was also named Mengite, by Brookes, who examined it in 1831. The same mineral was re-discovered by Shephard in South Carolina in 1837, and described by him under the name Edwardsite. Shephard was the first to discover the true chemical nature of the mineral, finding it to be a phosphate of the cerium metals. Edwardsite was shown to be identical with monazite by Gustav Rose in 1840, but it was not till 1877 that Lévy's Turnerite was shown by Pisani to be also identical with monazite.

Monazite is very widely distributed as what is known as an accessory mineral in granites and in acid rocks which have been formed under the influence of very high temperatures and pressures in the early history of the earth's crust. Almost all such rocks contain tiny crystals of monazite, distributed throughout their mass, whilst occasionally larger quantities are found in veins.

All these rocks are extremely old, and they have therefore been in many cases greatly eroded and worn away during the course of geological ages. The action of rain and wind, of frost and summer heats, of vegetation and percolating water, though insignificant in a century, will, in the course of millions of years, destroy the most resistant rocks, wear away the everlasting hills, and level the most mighty mountains. When erosion occurs on such a scale, some of the minerals forming such rocks are altered and decomposed chemically, being dissolved or washed away in their new forms; others, chemically more resistant, retain their individual qualities, and remain *in situ*, or are collected by the action of winds or moving waters into new deposits. Monazite, together with others of the minerals which occur in granites and other old acidic rocks, is extremely resistant chemically, and in the gradual wearing away of the parent rock it has survived unchanged. The deposits into which it has been collected are now known to us as monazite sands, and form to-day the commercial source of the mineral, and of the thorium which it contains.

Sands rich in monazite are generally found in or near river beds, in estuaries or alluvial plains which were once the beds of rivers, at the bases of sea cliffs or on shallow coasts or islands, in all situations, in short, in which they could have been deposited by the action of running waters. When the parent rocks in which the monazite was first formed were gradually destroyed, the lighter minerals and products formed by decomposition of the less resistant ones were removed first. The heavier minerals, which included the monazite, would be removed only by the action of strongly-running waters, and they would be dropped as soon as such flowing waters began to lose their velocity. The

action of running water, in fact, tends to sort out the various products formed from the parent rock, collecting them into deposits roughly according to their densities. The monazite sands therefore contain many of the heavier and more resistant minerals which generally occur in granites. Gold, for example, is a not uncommon constituent, in minute quantities, of such rocks, and is therefore generally found in the monazite sands. Many of the more resistant and dense minerals also are of value as gems, so that the monazite sands are frequently rich in gem-minerals.

The first important deposits of monazite sands to be generally recognized and worked for monazite for the manufacture of mantles were those of North and South Carolina in America, in which Shephard discovered his Edwardsite and first pointed out its true chemical nature. These deposits were worked commercially for the extraction of monazite, which is present to the extent of approximately 1 per cent, during the last few years of the nineteenth and the first few years of the present century, chiefly by the Welsbach Light Company of New York. Shortly after the extraction of monazite from these sands had been commenced, however, very extensive and much richer deposits were discovered in Brazil, and operations were started there by the German Thorium Syndicate and the Austrian Welsbach Company. These two latter companies arranged a working agreement with the object of securing control of the world's supply of monazite, for which purpose they began a price war. The American companies succeeded in keeping up a considerable output for some years, but in May, 1910, the German and Austrian companies lowered the price of the thorium nitrate made from the monazite to such a point that the American companies were obliged to suspend

operations, and from that time until the war started the Brazilian sands supplied the whole world.

The outbreak of war soon brought a realization of our dependence on Germany, and the American deposits were opened up again. By that time, also, rich deposits of monazite had been found within the British Empire, notably at Travancore in India, but it was found that

PLATE No. 11

MONAZITE SHORE DEPOSIT, TRAVANCORE, INDIA

Worked by Messrs. Hopkin & Williams (Travancore), Ltd.

the German syndicate had acquired control of the company which had been formed to exploit this field. The Travancore Minerals Syndicate was reconstructed in the early years of the war, due precautions being taken by the Government to prevent any possibility of foreign control in the future, and these deposits are now worked and thorium nitrate prepared by English concerns. (Plates 11 and 12.)

The Carolina deposits occur over an area of approximately 4,000 sq. miles, the monazite being found chiefly in the basins and valleys of the numerous streams which

rise in the South Mountains, and drain the Piedmont plateau. It was in this area that the methods of extracting the monazite were first worked out, and when other deposits were worked later on, the American engineers had already developed suitable means for this purpose. Another important area in the United States is that of Oregon, where the sands contain both platinum and gold. Operations to extract gold as well as monazite from these deposits were started in 1909, and a considerable amount of work had been done when a disastrous fire put a stop to the operations in 1910.

The Brazilian deposits are much more favourably placed and are much richer in monazite than those of the United States, and the monazite they contain is also richer in thorium, and therefore more valuable. The sands occur chiefly along the coasts of the provinces of Bahia, Minas Geraes and Espirito Santo, the largest being on the shores of a bay near the island of Alcobaca, on the southern coast of Bahia. Extensive inland deposits have also been found in the same provinces, and the mineral is common in the famous diamond and gold-bearing sands of Diamantina and Ouro Preto. Only the beach deposits, however, are worked for monazite, since these have been concentrated by the action of the tides to a greater richness in monazite, while transport in such localities by sea is cheap and easy. The Brazilian Government levies a very heavy tax on all monazite exported, and it was stated before the war that the Thorium Syndicate paid an amount equal to its net profit each year in royalties to Brazil.

The Travancore deposits are extraordinarily rich in monazite, the sands containing over 45 per cent of the mineral. The monazite is also unusually rich in thorium oxide, containing about 10 per cent as against

PLATE No. 12

NATIVES WORKING MONAZITE SAND ON THE SHORE, TRAVANCORE, INDIA

3 to 4 per cent in Carolina monazite. The deposits are thus of remarkable value, but owing to their location and the lack of transport, they cannot be worked cheaply until the region has been more fully developed.

(*b*) **Concentration of the Sands.** The methods adopted in treating a monazite sand to extract the mineral depend to some extent on the proportion of monazite it contains, but the general procedure still follows to some extent the methods first worked out in the Carolinas. They depend on two properties of the minerals of which the sands are composed, properties which are very different for nearly all of the individual minerals —density and magnetic permeability. The differences of density allow of the separation of the lighter minerals by means of running water—much on the lines of the method by which the sand deposits are formed in Nature. This process is known as washing, probably because in the early days it really was a sort of hand washing. In the crude original hand process, the sand is thrown on to a sort of sieve, fixed over the upper end of a long narrow trough. A jet of water is directed on to the sieve by one workman, the sand by this means being washed through it into the trough. A second workman continually turns over the sand in the trough and on the sieve, the water being allowed to flow continuously and fresh sand being thrown on to the sieve from time to time. The lighter minerals are washed along the trough and removed by the water whilst the heavier ones, with them the monazite, remain behind. The concentrate left at the end of each day's washing is collected and dried, either in the sun, or on stoves.

In the concentration by machine, the device usually employed is known as a concentration table, the type in common use being the Wilfley table. The sand is fed into a hopper by means of a moving belt, and falls

Plate No. 13

ELECTRO-MAGNETIC SEPARATORS

Used in the Extraction of Monazite from the sands at Travancore, India

automatically on to a table, which is kept in continual motion rapidly from side to side by machinery. The table is slightly inclined downwards, and a continuous stream of water flows over it. The table is of such a length that the particles, by the time they reach the lower end of the table, have been carried by the water, acting with the assistance of the shaking motion, to points along the width of the table corresponding with their densities, that is, from each region of the bottom of the table a definite set of minerals is carried off by the water, the heaviest from the side on which the sand is fed on, and the lightest from the opposite side, the intermediate minerals being distributed in between.

This density-concentration collects the monazite with the heavier minerals of the sand, from which it has next to be separated. The possibility of doing this mechanically was demonstrated by the American engineer Wetherill, who took advantage of the fact that not only minerals containing iron, but a large number of other minerals may be attracted by the magnetic field, if it be made sufficiently strong. In the Wetherill electro-magnetic separator used for monazite separation, the concentrates from the washing tables are carried in succession through four magnetic fields of increasing strength by means of moving belts. As the belt passes between the poles of each electro-magnet, the minerals attracted are withdrawn by the magnetic force from the remainder, and are caught against belts moving at right angles to the main belt, and just above it. These latter belts move very rapidly, so that they carry off the attracted minerals, and deposit them in bins placed to receive them. Other forms of the machine are in use, but the principle of all is the same. For monazite four different fields are used, the coarser monazite fragments being collected by the third, and

the finer by the fourth. In this way an almost pure monazite is obtained, suitable for the separation of the thorium.

An installation of electro-magnetic separators set up at Travancore during the war, for the extraction of monazite from the shore deposits, is shown in Plate No. 13. Plate No. 14 shows a type of machine in which the short moving cross-belts of the Wetherill separator are replaced by discs, which revolve above the main belt, and which can be adjusted (as shown in Plate 15) to divide the sand or powdered ore into six portions at one operation, each portion consisting of fragments less highly magnetic than those of the preceding portion.

(*c*) **The Separation of Thorium and Cerium from Monazite.** As already stated, monazite consists essentially of the phosphates of the cerium metals. All monazites contain small proportions, however, of the element thorium, which does not belong to the cerium group, and, in fact, chemically is not one of the rare earth elements at all. Monazite also contains small quantities of silica, together with very small proportions of other oxides. It was for a long time thought that thorium was not a real constituent of monazite at all, but was combined with the silica to form a mineral which was merely very intimately mixed with the monazite, but it has been found that all samples of the mineral contain thorium, and it is now thought to be present as a phosphate, and an essential part of the mineral. The proportion of thorium present varies considerably, some specimens containing as little as 1 per cent, others as much as 20 per cent ; the usual values are between 5 and 10 per cent. Since the mineral owes its commercial value entirely to the thorium it contains, the exact determination of the element is of great importance.

For use in the mantle industry, thorium is required in the form of the nitrate, and in a state of very high purity, since the light given by the finished mantle is very largely dependent on the accuracy with which the composition 1 per cent ceria with 99 per cent thoria is adhered to. The extraction of pure thorium compounds

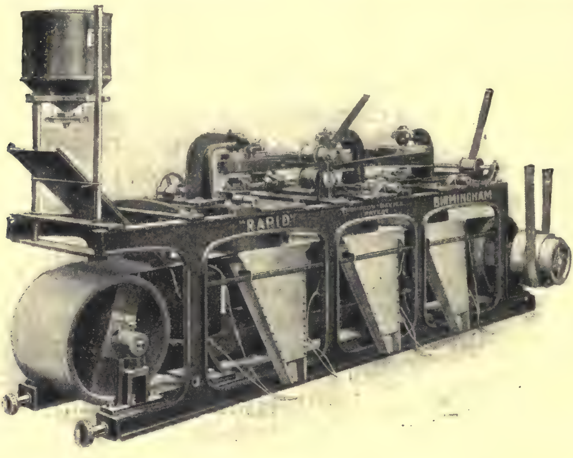
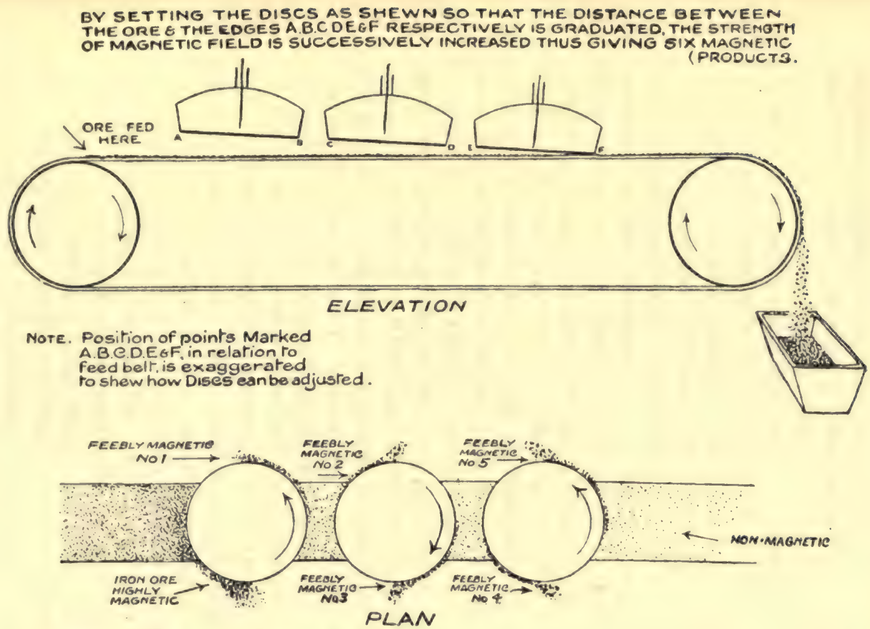


PLATE No. 14

ELECTRO-MAGNETIC SEPARATOR, DISC TYPE

As supplied by The Rapid Magnetting Machine Company

from monazite is a process of the greatest technical difficulty, and demands a degree of care which very few manufacturing processes receive, or could afford to pay for. Preparation of almost any substance in the state of purity in which thorium nitrate is required for the mantle industry would have been held to be impossible outside a scientific laboratory before the needs of the industry made it clear that such care



Rapid Magnetting Machine Co.

PLATE No. 15

DIAGRAMMATIC SKETCH

Showing working of the Separator shown in Plate No. 14

must be exercised if satisfactory results were to be obtained. It is remarkable how quickly scientific methods can be adopted in industry, once it is found that they are profitable.

The difficulty in extracting pure thorium compounds from monazite is due firstly to the small proportion of the element present, as compared with the much larger amounts of the cerium elements, and secondly to the great difficulty of completely separating thorium from these elements, which is a consequence of their chemical similarity: These difficulties have led to the adoption on an industrial scale of methods and operations formerly carried out only in the laboratory, methods involving numerous repetitions of similar operations, and such prolonged and extensive handling of the same material that in order to prevent the losses of valuable material becoming so great as to make the processes too inefficient for industrial use, it is necessary to ensure that each separate operation is carried out practically without any loss whatever. Thorium nitrate manufacture is, in fact, the application of the most laborious research methods to the factory scale, and it is almost safe to say that in no country besides Germany could such detailed and exhaustive processes have been brought into successful operation, at least before the war showed to what an extent Germany had secured a commanding position in the world's industries by just such minute and painstaking attention to detail.

The first stage in the chemical treatment of monazite is generally a prolonged treatment with strong sulphuric acid at a high temperature. The object of this is to transform the insoluble phosphates of which the mineral consists into soluble sulphates of thorium and the cerium elements, since it is necessary to have the substances in a soluble form before separation of the

elements can be undertaken. The sulphuric acid treatment is carried out in large cast-iron pots, which take a charge generally of about 5 cwt. of the mineral and twice that weight of strong oil of vitriol. The charge is heated for five or six hours, until the phosphates are completely decomposed. Since thick fumes of sulphuric acid are driven off, it is necessary to have the pots covered and provided with suitable fume pipes through which the fumes can be sucked by a fan.

An interesting by-product which can be obtained from monazite in this sulphuric acid decomposition is a mixture of radium and similar active bodies, which is of considerable value for medical purposes. The famous British chemist, Soddy, to whom many of the more wonderful discoveries in the province of radio-activity have been due, has shown that an extremely active substance, mesothorium, which has an activity equal to 300 times that of radium itself, can be extracted from monazite, together with radium, which also occurs in minute quantities in the mineral. The quantities of these substances which are present in monazite are infinitesimally small, being of the order of fractions of 1 grain per ton, but their commercial value is by no means negligible. Radium itself is worth something of the order of £30,000 per oz., and mesothorium, being so much more active, would probably command a correspondingly greater price.

After the sulphuric acid treatment, the residue is treated with water containing sulphuric acid, to bring the sulphates into solution. At this point the laborious separation of the thorium from the cerium elements commences. The procedure varies somewhat in different factories, and the precise methods adopted are generally kept secret. They consist in the treatment of the solutions with various chemicals which react with the

elements to differing extents, or which produce with them new compounds having different degrees of solubility. Their nature may be sufficiently illustrated by one or two examples, it being postulated in each case that no operation is complete in itself, but must be repeated laboriously in every detail many times before the desired effect is obtained.

One method of treating the solution of sulphates obtained after the vitriol treatment, for example, consists in adding very gradually, and with continuous stirring, a quantity of powdered magnesia. This has the effect of partially neutralizing the sulphuric acid, and allowing the insoluble phosphates to reform and separate from the solution. If the right quantity of magnesia has been added, and the necessary conditions faithfully observed, the precipitate will contain almost all of the thorium originally present in the monazite, together with some of the cerium elements. The precipitate is dissolved again in sulphuric acid and the precipitation with magnesia is repeated. Each repetition of this series of operations gives a precipitate richer in thorium, but no practicable number of repetitions would finally give a pure thorium precipitate, and other operations have to be undertaken.

For further separation of the cerium elements, advantage is taken of the fact that the carbonates of the latter are less soluble in sodium carbonate (the ordinary washing soda of the housewife) in water solution than is thorium carbonate. The phosphate precipitate is therefore converted into an oxalate or hydroxide precipitate, by appropriate chemical means (the object being to remove completely the phosphoric acid, which makes the substances insoluble in anything but strong acids) and boiled for a long time with a strong solution of sodium carbonate. This tends to dissolve

the thorium, and leave the cerium elements undissolved, but nothing like a complete separation can be effected in one operation. The mixture is therefore filtered, to remove the undissolved carbonates of the cerium elements, and the thorium thrown down again from the solution by means of sodium hydroxide, the whole series of operations being then repeated until the thorium compound finally obtained is sufficiently pure to be subjected to the final refining processes.

The final purification is effected by what is known as the method of fractional crystallization, in which advantage is taken of the fact that certain classes of compounds of the rare earth elements exist, for which the various members have different degrees of solubility in water. The class of compounds used for the final purification of thorium by this method is the sulphate class, though other series of compounds have been proposed and employed. Thorium sulphate is considerably less soluble than the sulphates of the cerium elements, and if the necessary conditions are observed, the cerium elements can be completely removed without much loss of thorium by three or four repetitions. The thorium carbonate or hydroxide obtained after the carbonate fractionation is dissolved in hydrochloric acid (the spirits of salt of ordinary use) and the exact amount of sulphuric acid necessary to cause the separation of the whole of the thorium as sulphate is added. The proportion of compounds and acids to water and the temperature must be carefully regulated, since extended research has shown that the properties, and particularly the solubility, of thorium sulphate are very much affected by quite small changes in these factors. The sulphates of the cerium elements remain to a large extent in solution. The separated thorium sulphate is again converted into hydroxide,

and the series of operations repeated, three or four repetitions being generally sufficient to give almost chemically pure thorium sulphate.

The pure thorium sulphate so obtained is boiled with sodium hydroxide, the insoluble hydroxide of thorium so formed is washed repeatedly with distilled water, and the pure thorium hydroxide so obtained finally dissolved in the required amount of nitric acid, to give the nitrate, which, after drying, is obtained in the form of a pure white crystalline salt, suitable for use in mantle manufacture, and beyond doubt one of the most highly purified chemicals prepared at the present time for industrial use.

In addition to thorium nitrate, cerium nitrate is also required for the manufacture of mantles, though in very much smaller quantities. Since monazite is primarily a compound of the cerium elements, there is no lack of raw material for the preparation of the cerium salt, the residues obtained in the preparation of thorium nitrate being far more than sufficient to supply all that can possibly be used. The disposal of the very large quantities of compounds of cerium and the allied elements which are produced in the working-up of monazite is, in fact, one of the outstanding problems of the rare earth industry. In spite of a great deal of work, very few profitable outlets have been found for the very large quantities which are available. The most important use yet found was devised by Welsbach himself, who found in the course of his researches that almost all the alloys of cerium with the more common metals possess the property of emitting glowing particles very easily when scratched or struck. These pyrophoric or spark-giving alloys have found some application in the manufacture of lighters for smokers, which consist essentially of a toothed iron wheel which

is caused either by means of a spring operating when the device is opened, or by hand, to exert friction against a fragment of the pyrophoric alloy, the sparks so produced falling either on to prepared tinder, or on to a wick fed with some suitable easily-ignited liquid.

The quantities of cerium required for these lighters are very small, and the number of lighters used is not enormous. Similar devices have been brought out for ignition of gas for ordinary household use, but they have found little favour. The alloys have been suggested as a means of securing automatic ignition in incandescent lighting, but no sufficiently reliable device has so far been produced. It was also suggested that such alloys would afford a very safe and easy means of igniting the Davy safety-lamps used in mines, but it was found that no means could be obtained for preventing the sparks from flying outside the wire-gauze shield of the lamp.

Cerium has also been suggested for use in aluminium casting, a small quantity being said to act as a cleansing agent, making the castings cleaner and stronger. Compounds of cerium have been proposed for use in the preparation and application of dyes, for reducing over-developed negatives in photography, in the mixing of emulsions for colour-photography, in tanning, in various chemical industries, in making flashlight-powders and arc-lamp electrodes, and so on, but none of these applications has been found of much value to the rare earth industry. Cerium oxalate has been used to a small extent in medicine as a sedative, but here again the application is unimportant from the industrial point of view. Some important uses will probably be found in the future, for cerium is an element of valuable chemical properties ; a really useful commercial application would be of importance in the rare earth

industry, and would materially reduce the price of thorium nitrate.

The cerium nitrate required for the manufacture of mantles is prepared from the mixed carbonates of the cerium elements formed as a precipitate in the separation of thorium by the carbonate method described above. These are dissolved in hydrochloric acid, and oxalic acid is added to the solution. This separates the cerium elements as the insoluble oxalates, foreign elements remaining in the solution. The oxalates are filtered off and very strongly heated, the effect being to decompose them, and to leave behind the oxides, which are then dissolved in nitric acid. The required amount of ammonium nitrate is added to this solution, which is then concentrated by boiling to the point at which the double salt, ceric ammonium nitrate, will separate on cooling. This salt is less soluble than the nitrates of the other elements of the cerium group, so that the process is one of fractional crystallization. The separated salt is dissolved again in hot water, and the crystallization of the cerium compound repeated until it is sufficiently free from compounds of the other elements, when it is strongly heated to transform it into the oxide, which is then dissolved in nitric acid, and the solution evaporated until the dry, pure nitrate is obtained, ready for use in the preparation of incandescent mantles.

CHAPTER IV

THE MANUFACTURE OF INCANDESCENT MANTLES

(*a*) **Preparation of Cotton and Ramie Fabrics.** The method of manufacture patented by Auer von Welsbach in France in 1884 and in Germany in 1885 was briefly as follows : A suitable vegetable fabric is chosen, woven from threads of about 0·22 mm. (less than one-hundredth of an inch) in diameter. The patents covered every kind of vegetable or animal fibre, that is every suitable kind of fabric then in existence, and were made so comprehensive in every particular that in the existing state of knowledge at that time the legitimate manufacture by any other person or concern without the permission of the Welsbach interests was impossible. The fabric is prepared in cylindrical form, and is then washed, first with a dilute solution of hydrochloric acid, and after that with distilled water. It is then allowed to remain until saturated in a water solution containing 30 per cent of the selected rare earth salts. After saturation it is wrung out until it contains only the required amounts of the chemicals, dried, and cut into suitable lengths, which are determined by the size of the mantle required, care being taken to allow for the shrinkage which occurs in the subsequent operations. One end of each cylinder is then drawn together by means of a platinum wire, and the mantle is hung from a side support over a burner. The incineration should completely burn away the cotton or other fabric, leaving an ash or skeleton in the exact form of the fabric before saturation, but considerably smaller. At this stage the mantle is extremely fragile,

the head in particular being too weak to support the remainder for any considerable length of time under any shock or strain. The head is therefore painted over with a solution containing compounds of various metals, aluminium, magnesium and beryllium being specified, and the mantle after drying is formed by means of a very hot flame. This operation not only strengthens the skeleton very considerably, increasing its resiliency and toughness, but gives it the symmetrical form required. The mantle was at first sent out in this condition, and it was not until 1886 that the protecting stage of collodinization was patented. During the next few years, many additional patents were taken out to protect various improvements. The expensive platinum wire used for drawing the head together, and supporting the mantle in use, was replaced by asbestos thread. The earlier method of supporting the mantle on the burner in use by means of a piece of platinum supported from the side of the flame was discarded, a central rod of magnesia being substituted. Ramie was introduced in 1898, and the use of artificial silk was patented in 1894, though it was not until 1903 that this last fabric was successful.

In the actual process of manufacture, the greatest care must be exercised at every stage. The preparation of the nitrates of thorium and cerium required, as already described, must be painstaking to a degree if good results are to be obtained, and the actual process of making the mantle from these chemicals must be equally careful and conscientious. The fabric employed must be carefully chosen, in the case of cotton only long-staple material of guaranteed quality and specified thickness of thread being permissible. When ramie is used, the fibres must be freed from all traces of gum or resin by prolonged heating with caustic soda under

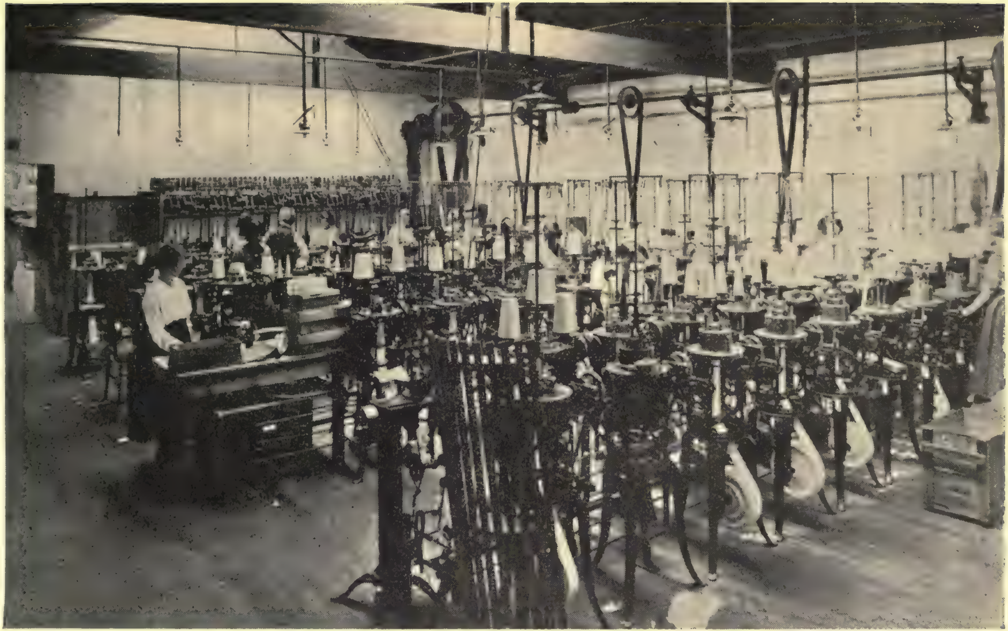


PLATE NO. 16

KNITTING SHOP AT THE FACTORY OF MESSRS CURTIS'S AND HARVEY, EARLSFIELD

The selected fabric is being woven into cylindrical form

pressure ; after thorough washing and drying, the fibre is bleached and again cleaned by picking and teasing, and finally combed and spun in the usual manner. When these fabrics come into the mantle factory, they must again be treated to free them from all dirt and grease, and from every trace of mineral ash. For this purpose they are first washed again with alkali and then with soap ; mineral ash is removed by treatment with hot dilute hydrochloric acid, the last traces of this being washed out with distilled water. To obtain good mantles, it is necessary that the mineral matter in the fabric be reduced to less than 3 parts in 10,000. Ordinary tap water cannot therefore be used for washing, and even the distilled water used must be kept so carefully that there is no risk of its becoming contaminated. Traces of iron, which in small quantities constitutes the commonest impurity in ordinary products, have an especially bad influence on the light-emitting power of the finished mantle, and it is therefore necessary to prohibit the use of any iron tools and appliances in the handling of the fabric. After the final washing with distilled water, the fabric is wrung out in a centrifugal machine, and dried by passing over wooden rollers in dust-free chambers through which warm purified air at a temperature of about 100° F. is drawn.

(*b*) **The Preparation of Mantles from Ramie and Cotton Fabrics.** The washed and dried fabric is now ready to receive the rare earth salts which are to leave the oxide skeleton which constitutes the finished mantle. Before impregnation, however, it is cut into lengths corresponding to the dimensions of the finished product. These separate lengths are soaked in a solution of the nitrates of cerium and thorium in the required proportions in distilled water. Owing to the very great effect on the light-emitting power of the mantle of even

the slightest deviation from the standard composition, it is necessary to prepare the solution with the greatest care, and the salts must be weighed out and the water measured with the degree of accuracy which dispensers use when weighing out deadly drugs, or which jewellers use in weighing gold and precious stones. It is usual to dissolve the two salts separately, and then to mix the separate solutions in the required quantities.

The ordinary upright mantle made from cotton is about 4 inches in length, and the dried fabric from which it is made weighs before impregnation about one-sixth of an ounce. The weight of the ash of rare earth oxides which forms the finished product is about one-sixtieth of an ounce, which corresponds to about one-thirtieth of an ounce of the nitrates, or, since these are used in about 30 per cent solution, to about one-ninth of an ounce of the solution or lighting fluid. The cotton fabric must therefore be allowed to take up about two-thirds of its own weight of solution. The ramie fabric for an ordinary upright mantle weighs only about one-tenth of an ounce and since the same weight of ash is required in the final skeleton, this fabric must take up slightly more than its own weight of the solution. The weights of rare earth oxides required for the different types of mantles have been determined by experience ; if more than the above quantities are used, the light-emitting power is reduced without any corresponding gain in strength, whereas if smaller quantities are used, though the light-emitting power is increased, this being greater the lighter is the skeleton, the strength is so much reduced that in use the mantles become too fragile.

The time required for immersion of the fabric in the lighting fluid is from 2 to 5 minutes in the case of cotton and ramie fabrics. The pieces are then removed from the solution and are passed between the rollers of a

small wringing machine. The pressure between these rollers must be very carefully adjusted, so that the fabric retains just the quantity of the lighting fluid required. The separate lengths of impregnated fabric are now drawn on to glass forms, arranged on stands, and dried in dust-proof rooms by hot air. The temperature of the air, which largely controls the time required for drying, must be chosen so that the moisture is not too rapidly driven off, since quick drying causes considerable shrinkage, which has the effect of making the oxide skeleton very fragile. The temperature usually chosen is about 80° to 85° F., and the time required under these conditions is from 3 to 4 hours.

In the older patterns of mantles, the asbestos thread by which the oxide skeleton is supported in the flame was threaded through a band at the head of the fabric. This band was at first formed simply by turning down or doubling over the fabric itself, but later it became usual to sew on a separate strip of tulle or gauze. The doubling over or sewing on was done before the impregnation of the fabric. In the later patterns, however, this was not done, the mantle being supported by asbestos threads inserted at a later stage.

To enable the head to support the weight of the mantle, it is strengthened by a secondary impregnation carried out after the main operation, but at the head end only. The materials used for this strengthening are usually the nitrates of aluminium and magnesium, generally in equal proportions by weight, dissolved in water to form a solution containing approximately 40 per cent by weight of the mixed nitrates. Small quantities of other chemicals are sometimes added to this strengthening solution, together with a little colouring matter, so that it may be seen as it is applied, and care taken to restrict it to the head end only.

PLATE No. 17

MANTLE MODELLING SHOP AT THE FACTORY OF MESSRS. CURTIS'S AND HARVEY, LTD., EARLSFIELD

The impregnated lengths of fabric are being shaped before being burned off to obtain the skeleton of Rare Earth Oxides

The solution is applied to the dried impregnated fabric from mechanically held pads, which are kept saturated with the liquid by means of compressed air acting on the vessel in which the solution is contained. The mantle is then again dried, but this time more quickly, since there is not now the same danger of shrinkage. This operation is sometimes known as Fixing.

The next operation is to give to the mantle its shape. For the ordinary upright form, the head is sewn together with threads of carefully selected asbestos, so that the fabric is drawn nearly but not quite together. The opening left is roughly circular in shape, and about two-fifths of an inch in diameter. The asbestos thread is carried several times across this opening, to form the framework from which the mantle is supported in use. During the last few years, machines have been employed for these operations, but at first they were carried out entirely by hand, and hand work is still used for the best mantles. In some patterns, these supporting asbestos threads have been replaced by metal rings, made from sheet iron plated with aluminium, these being attached to the fabric by means of asbestos as before.

For inverted mantles, the strengthening of the head is carried out to a rather greater depth, and this strengthened end is turned down and sewn to form a band, through which an asbestos thread is drawn. By means of this thread, the head is secured to a ring of the necessary size, made of magnesia or very carefully-prepared clay. The lower end is then drawn together into the form of a hemisphere by means of threads drawn through the meshes of the fabric, the end is cut off, and the mantle pressed into permanent hemispherical shape on a wooden former. The mantle is now stamped with any desired markings, the solution

used being chosen to leave a permanent impression after the next or " burning-off " operation.

Burning-off is generally carried out mechanically, large numbers of mantles being treated in one operation. For the very best mantles, however, the operation is still carried out by hand with each mantle separately, since at this stage the mantle receives the treatment which determines its value in use, and it is possible for skilled operators to allow for any variations in the mantle at this point, due to differences in the fabric or to variations in the washing, impregnation, or subsequent operations. It is, of course, exceedingly difficult to secure absolute uniformity in such a product, where the most minute differences may have enormous effects on the finished mantle, and it is for this reason that burning-off by hand is still carried out for the best and most expensive mantles.

The effect secured by this operation is the complete removal of the material of the fabric itself, and the transformation of the nitrates of the thorium and cerium into the oxides of these elements, which themselves form the mantle proper. The two changes proceed simultaneously, the decomposition of the nitrates assisting the complete destruction of the fabric, since in the transformation of the nitrates to oxides large quantities of oxygen are evolved. The oxides left retain the exact shape of the original fibres, but the skeleton so formed is extremely fragile. In order to give it strength and elasticity, the mantle, after burning-off, is subjected to a blowpipe flame of gradually increasing intensity ; this operation, which is known as " Shaping," may be carried out immediately after the burning-off, or when modern mechanical methods are used the two operations may be carried out together. The burning-off must be carried out under an

efficient ventilating hood, to carry away from the operatives the poisonous nitrous fumes given off during the decomposition of the nitrates, and the operatives must be provided with green glasses, or shielded behind shades of green glass, to protect their eyes from the intense glare of the mantles under the shaping action of the blowpipe flame.

The fabric ready for burning-off is supported by the asbestos fibres threaded across the head, in the case of an upright mantle, or by the magnesia ring in the case of an inverted mantle, and a flame is applied to the head. The flame is removed when the mantle has burned halfway down, the weight of the lower unburned portion being sufficient to prevent shrinkage, even though the burning, under the action of the flame applied, is rather rapid. When the mantle has been burned down halfway, the flame is removed, and the combustion allowed to proceed of itself, which it does very steadily, and at a much slower rate. The bottom half burns off without flame, a uniform glow spreading steadily downwards. The shrinkage is in this way kept as uniform as possible, and the fragile oxide skeleton is not subjected to undue stress. The mantle is now removed and placed over a radial blowpipe, that is, one of which the flame spreads out horizontally in a circle all round the burner. The flame is started with a relatively small pressure of air, and the holder supporting the mantle is rotated continuously, being at the same time slowly lifted, so that the flame of the blowpipe acts in succession on every part of the skeleton. The pressure of air supplied to the blowpipe is at the same time steadily increased, so that the flame actually exerts a pressure on the mantle, and shapes it into a uniformly rounded product. It will be readily understood that these operations require great care and

experience, since it is possible by suitable manipulation at this stage to compensate for minor irregularities or faults in the earlier processes, whilst any imperfections which may arise in the burning off and shaping are themselves irreparable, and must lead either to the rejection and complete loss of the mantle, or to serious defects in use. It is on account of the critical nature of these operations that manufacturers prefer to have them carried out by hand, at least for those mantles for which absolute reliability is required. When machinery is employed, the two operations are usually carried out together, the mantles being suspended in rows of ten, on wire shapers, from which they are gradually withdrawn as they are lifted and rotated by the apparatus.

The mantles are now ready for use, and during the earlier years of the industry they were generally sent out without further treatment. As they are very fragile, however, it was soon found necessary to protect them in some way, and the method of collodinization was devised by Auer, and protected by patent in Germany in 1886. It was found, however, that for export purposes, and for some cases in which the product might be subjected to unusually rough handling, the protection afforded by collodinization was not sufficient, and for some years mantles for these markets were packed and dispatched without the burning-off and shaping operations, these being left until the mantles were actually to be brought into use on the consumer's burner. Most of the early artificial silk mantles, for use with high-pressure gas especially, were sent out in this way, the pressure of the gas at the burner being sufficient in these cases to secure very efficient burning-off and shaping. Inverted mantles also can be readily burned off on the ordinary consumer's burner, but with

upright mantles the operation is not so satisfactory, and mantles sent out in this way were generally of shorter life and lower illuminating power.

(*c*) **The Preparation of Mantles from Artificial Silk Fabrics.** The importance of artificial silk to the mantle industry doubtless originated in the fact that it was a new artificial fabric, the use of which was not covered by the Welsbach patents, so that its introduction afforded the first possibility of manufacturing incandescent mantles for firms and individuals outside the Welsbach concerns. The new fabric was first shown to be a commercial possibility about 1890, and in 1892 a patent was granted for its use in the preparation of mantles, so that no time was lost in endeavouring to take advantage of the opportunity it afforded.

The credit for first observing the possibility of preparing artificial fabrics from cellulose appears to belong to an Englishman named Swan, who showed at the London Exhibition of 1884 fabrics prepared from solutions of nitrocellulose in acetic acid. It is interesting to note that since Welsbach's first patent was taken out in France in that same year, the new fabric, the only one of which he did not protect the use, had already been foreshadowed at the time his patents were being drawn up. Swan's process appears never to have been seriously taken up, but it probably inspired the successful work of Chardonnet, which was begun about 1885, and brought on to a commercial scale some five or six years later. Chardonnet employed the same material as Swan, namely, collodion or nitrocellulose, which is prepared by the action upon cellulose, in the form of cotton waste or paper pulp, of a mixture of nitric and sulphuric acids of certain strengths. The collodion so obtained resembles the cellulose from which it is prepared very closely in physical properties, but

differs from it firstly in being rather dangerously inflammable, and secondly in being readily dissolved by a variety of solvents. The solvent employed by Chardonnet was a mixture of ordinary alcohol with ether. The very viscous liquid obtained by dissolving the collodion in this mixture was forced, in Chardonnet's first process, through very tiny jets into water. The water removes the alcohol and ether almost instantaneously, causing immediate coagulation or solidification of the collodion in the form of a very thin thread or filament. As the solution is forced through the jet continuously, a continuous coherent filament is obtained, which is wound on to a spool as it is formed. A very important proportion of the cost of the fabric was incurred for the alcohol and ether used as solvents, and the process was soon modified so that these might be recovered. In the new method, the collodion solution emerged from the jets into heated chambers, instead of into water. At the high temperatures used the solvents were evaporated, leaving a solid filament as before ; the ether and alcohol vapours were drawn by fans through recovery towers, in which they were condensed by cooling, or by some absorbing liquid circulating through the towers, and so recovered. The collodion filaments are woven into threads, which are then treated chemically to render them less inflammable.

Several other methods of making artificial silk have been elaborated since the first introduction of the collodion process. About 1900 the Pauly method was proposed, in which cellulose is dissolved directly in a solution prepared by passing air through a solution of ammonia to which copper turnings have been added. This solution is then forced through jets into a bath containing acid, which causes the cellulose to assume the solid form again. In the Viscose process, which

was protected by patent in 1893, cellulose is treated first with soda and then with carbon disulphide, yielding a compound soluble in water. This water solution is forced through jets as before into a bath containing acid, which again precipitates the cellulose. More recently, acetate silks have been prepared from cellulose acetates, materials which became of great importance during the war from their use in the preparation of dopes for aeroplane wings. Cellulose acetate is obtained from cellulose, after a preliminary treatment with dilute acid, by the action of pure acetic acid and acetyl chloride, generally in presence of sulphuric acid. The products obtained vary enormously in their physical characters, especially in the extents to which they are dissolved by various solvents, but under suitable conditions compounds are obtained which dissolve readily in certain organic liquids, the solutions being forced through jets, and the cellulose acetate obtained again as solid filaments by means of baths of suitable substances.

The acetate silk has the advantages of non-inflammability, great strength, resistance to water and very high resistance to the electric current, but it is too expensive for ordinary use as a fabric, or for the manufacture of incandescent mantles. For this latter purpose, the Pauly and Viscose silks are the most suitable, though it was with the Chardonnet fabric that the first artificial fibre mantles were made. As early as 1892, that is, within two years of the first publication of Chardonnet's process, a patent was taken out in Belgium by Schlumberger and Sinibaldi, who found that the new fabric would readily take up the lighting fluid. Their patent, however, does not appear to have been completed, and their observation attracted little attention. Attempts were made by De Mare in 1894 and Knöfler in 1895 to

prepare mantles by adding to the collodion solution before forcing through the jets the necessary quantities of thorium and cerium nitrates, but owing to the great viscosity of the solutions, it was found impossible to get uniform mixing of the salts, and no satisfactory mantles could be prepared from the resulting threads. In 1901 and 1903 patents were granted to Plaisetty, which protected the impregnation of the finished artificial silk fabric with thorium and cerium nitrates, and a subsequent treatment with ammonia solution, the fabric being then dried and burned off as usual. This method was found to give excellent results, and the manufacture of mantles from artificial silk was started soon after on a commercial scale.

On account of its absolute uniformity, and the almost complete absence of mineral ash, artificial silk forms an ideal fabric for this purpose, and requires no preliminary treatment before impregnation. On account of its solid structure and colloidal character, the fabric takes up the lighting fluid very slowly, and it is found desirable to allow it to remain as long as half-an-hour in a warm solution containing 50 per cent of the rare earth nitrates. It must also be dried very slowly, and subjected to a "Fixing" treatment with ammonia before burning-off. Owing to the extreme lightness of the fibre, the proportion of organic matter to the nitrates present is much smaller than in the case of fabrics of ramie or cotton, and under these circumstances the burning-off becomes almost explosive in violence, and injures the structure of the mantle, if the fabric containing the nitrates is burned off directly, as in the case of cotton and ramie. The action of the ammonia, however, converts the nitrates into hydroxides, and the burning-off then takes place quietly and easily, the mantles obtained being extremely strong and elastic.

(*d*) **Collodinization of the Finished Mantles.** The process of collodinization consists simply in covering the fragile oxide skeleton with a thin film or layer of collodion, which tremendously increases its power of resisting shock and vibration. The ash skeleton left after the burning-off and shaping operations have been carried out is dipped into a solution of collodion in suitable organic liquids. A small proportion of camphor is generally added to the solution, in order to prevent shrinkage of the mantle on drying. The solvents first used were alcohol and ether, which readily dissolve collodion when mixed in suitable proportions. The mixture of these solvents, however, on account of their great volatility and combustible nature, is extremely inflammable, and its use involves great risk of fire or of vapour explosions, unless the most stringent precautions are employed and the greatest care exercised in using them. The ether-alcohol mixture, however, has the advantage that the mantle after dipping is very quickly and easily dried, and the vapours of the solvents may be drawn away by fans and recovered, as in the Chardonnet process, in which collodion is employed to make artificial silk, being dissolved in the same mixture.

On account of the inflammability of the ether-alcohol mixture, these solvents are sometimes replaced by a mixture of methyl-alcohol and acetone, which are both organic liquids obtained in the distillation of wood. These give a less volatile and consequently less dangerous solution, but drying is, of course, slower than with the ether-alcohol mixture.

The collodion solutions used for the dipping of mantles are very similar in composition to the mixtures used for the manufacture of celluloid. The latter material is also prepared from collodion, usually also

with the addition of camphor, the quantities of solvents used not being sufficient completely to dissolve the collodion to the liquid condition, but only enough to soften and gelatinize the mass, so that it can be moulded into any desired shape, the solvents being removed again by gentle heating after the articles have been pressed or moulded, and generally recovered by means of towers, as in the collodinizing of mantles, and the manufacture of Chardonnet silk. Collodion is, in fact, a material of considerable commercial importance, being employed in the manufacture of films for cameras and cinematographic apparatus, as well as in the preparation of all kinds of fancy and toilet articles. It was one of the first easily and cheaply prepared synthetic materials which could be moulded and pressed into any desired form, and as such found very wide application, but its very high degree of inflammability is a grave deterrent to its use, and has been the cause of several accidents.

The collodinized mantle, after removal of the solvents, is cut to length on a trimming machine, and is then packed for sale. The collodion film which protects the delicate oxide skeleton remains until the mantle is brought into use on the consumer's burner, when, at the application of a match, it ignites instantly, and burns completely away, leaving the mantle in the condition to which it was brought in the burning-off and shaping operation in the factory.

CHAPTER V

THE MODERN METHODS OF LIGHTING COMPARED

THE selection of a particular system of lighting will generally be governed by two main considerations—firstly by the system of supply available, and secondly by the question of cost. Considerations of health and cleanliness, resting on the effect of the gases produced by combustion, ventilation effect of the particular method adopted, the soiling effect of solid particles or hot gases produced in combustion, etc., will also receive considerable attention, and for indoor domestic lighting may become the deciding factors. The magnitude of the illumination required does not under modern conditions exercise the same bearing on the selection of a system as was the case until recently, since the various methods available can nearly all be adapted to units of any illuminating power normally required, and can be rendered suitable for even the most exposed conditions. The flexibility of the various systems is illustrated by the different applications to lighthouse illumination, and to the illumination of exposed lightships, floating buoys, unattended lights at sea, and so on. Thus, gas and oil incandescent systems, as well as the electric arc system, are employed in different lighthouses, whilst for unattended buoys and coast lights not only the oil and oil gas incandescent systems, but acetylene and oil gas lighting with the ordinary burners are also employed with satisfactory results.

(*a*) **The Sources of Supply.** The sources from which selection may be made for any lighting installation

may be classified for all practical purposes under three heads, namely, oil, gas and electricity. The classification is very rough, as many systems are in use which might be placed under any two of these heads, as, for example, the use of petrol to run an air-gas system or an electric generator. Generally, however, it may be used for the purposes of discussion, with the understanding that the heads of division refer to the source of energy supplied to the system—thus, an aerogene system and a petrol engine-dynamo generating set would both come under the head of oil supply.

(1) Oil. For all practical purposes the oils used for lighting consist of petrol and kerosene or paraffin, the lighter fractions of the various petroleums. Petrol is unsuitable for direct use in lamps, chiefly because its high degree of inflammability renders it very dangerous, and makes the flame very smoky. For the aerogene systems, however, in which a mixture of air and vapour is obtained by drawing a current of air over the spirit in a suitable apparatus, the mixture being then burned either directly for illumination, or in a burner adapted for incandescent lighting, the great volatility of petrol and the richness of its vapour render it a very suitable material. Very reliable systems of this nature are in use, both for heating and lighting, in country houses and in localities in which no other supply is available ; they are clean and simple in operation, though, of course, intelligent manipulation is necessary, and the cost of running is somewhat high at the present cost of petrol. The chief objections to these systems are the capital cost, which is generally heavy, and the necessity for regular attention and intelligent handling. The average citizen nowadays prefers to press a switch or turn a tap to obtain his needs wherever possible, and the demands of a domestic appliance requiring only moderate

care and attention become exacting even to the energetic in the present strenuous times.

Both petrol and kerosene are employed as sources of energy in the motor-generator lighting and heating systems. In these, the oil is supplied to an internal-combustion motor, directly connected with a dynamo, from which current at any required pressure and density is obtained. Such sets are generally provided with a battery of accumulators to receive and store up the energy when it is not being used, or only being partially used, for lighting or heating, and to augment the dynamo at peak loads. Some are so constructed that the motor is started automatically as soon as a light is turned on, but in general they must be started up independently. They find employment where relatively large installations are required, and where cost and the necessity for skilled attention are not of first consideration. They have the great advantage that they will supply electricity for heating, and for such domestic appliances as vacuum cleaners, toasters, fans, flatirons, etc., but both first cost and running cost are high, and regular skilled attention is absolutely necessary if they are to be kept in good condition.

It is worthy of note that both petrol and kerosene were originally by-products in the petroleum industry. Young's first distilling plant was built to obtain lubricating oils only. The development of oil lamps provided a lucrative outlet for the kerosene, whilst the petrol remained for a long period almost a drug on the market. The introduction of the internal-combustion engine, however, provided an effective demand for the more volatile fractions, a demand which has grown with such giant strides in recent years that it is becoming again difficult for the oil refiners to find outlets for the kerosene which is separated from the petrol.

The oldest and best-known use of oil in illumination is, of course, direct combustion by means of a wick in a single lamp. Until the introduction of the metal filament lamp and the incandescent light, this was by far the cheapest method of lighting in general use, both in first cost and in running cost, and was especially favoured where a cheap and moderate illumination only was required ; for nearly a century it remained the only practicable efficient form of lighting where no gas was available, and the cheapest even where gas could be obtained.

Lamps from a fraction of 1 candle-power up to 30, 40, 50, or even 100 candle-power are now available, and for special uses, e.g. for lighthouses much greater illuminations have been obtained. In general, however, lamps of 7 or 8 to 20 and 25 candle-power are employed, these being more especially suitable for ordinary domestic use. Such lamps require a certain amount of care and attention in cleaning and filling, and in trimming and replacing the wicks. Without this attention, they easily become dirty, smoky and malodorous, defects generally alleged against them by our citizen of to-day, with his finger on the electric light switch or the gas tap. There is also a certain element of danger from fire in the use of oil lamps, though with ordinary care it is trifling enough. With the introduction of the incandescent mantle and the metallic filament lamp, the ordinary oil lamp has gradually been driven to those localities in which no gas or electricity are available.

A more recent form of lighting by means of paraffin is the oil incandescent lamp, which is coming into increasing favour where strong illumination is required and gas and electricity are not readily available. From the domestic point of view, it is liable to the denunciation

of the average citizen probably to a greater extent than the older type of oil lamp, and from the same causes, for this type of lamp can hardly yet be considered to have reached its most satisfactory development, and is liable to smoke and smell and spoil its mantle unless carefully handled, whilst it generally has to be coaxed into smooth working when first lighted. For detached outside lighting, and even for storm and hurricane lamps, it is coming into favour, whilst it has been in use for over twenty years in lighthouse installations. In these, however, compressed air is used, and skilled attention is always available, two aids to efficiency not generally enjoyed in the average household.

The above summary of the various methods by which oil may be used in lighting suffices to show that while it may be—one might almost say, has been—adapted to all modern needs, the cheapest and most promising system in which it may be employed, the oil incandescent lamp, appears to be in practice unsatisfactory for ordinary lighting requirements. Probably this is largely due to the difficulty of designing a really efficient lamp, but even when the best possible lamp has been devised, there will still remain the human factor—intelligent attention will occasionally be required. The necessary attention to gas and electric lamps and fittings is generally provided, for a small rental charge, by the supply companies. Possibly in the future the oil supply companies may find it profitable to organize such a service—some of them do it already, for example, in connection with lubricating oils. Certainly if the householder were relieved of his troubles in this direction, oil incandescent lighting would more easily find favour, and with more efficient lamps it might well have the advantage in cost.

(2) Gas. Since its inception in the early years of the nineteenth century, the gas industry has made truly wonderful progress, and to-day there is no large town in England, and hardly a small one, which has not its own gasworks, with pipes laid on, or available to be laid on, to almost every house within its borders. The number of gas companies at work in England and Wales is almost 1,000, and in addition there are about 250 gas undertakings in the hands of local authorities. Scotland has a total of about 250, and Ireland about 100 gas undertakings, making a total for the British Isles of about 1,600. Gas is therefore available for lighting and heating to the great majority of people, and especially to almost every inhabitant of a town.

The method at present employed for the production of gas from coal is known as High Temperature Carbonization, as against the process of Low Temperature Carbonization, which is being so strongly advocated at the present time. In a typical modern gasworks, coal is heated in "Retorts" made of highly resistant material, until no more volatile products are driven off, the residue left in the retort being coke. Retorts are usually about 10 ft. long, and are built into brick settings in a vertical or inclined position. Each retort takes a charge of about 3 cwt. of coal, which is completely carbonized in about eight hours. Part of the coke produced is used for heating the retorts, arrangements being made for the required amount to fall directly from the retort, when the charge is finished, into the furnace below. This coke is already at a red heat, and is used to heat the next charge in the retorts. The remainder of the coke, which is not required for the furnaces, is removed by means of endless conveyors travelling below the retorts, and is carried outside the

retort houses, being quenched *en route* by means of water.

The distillation of coal yields, besides gas and coke, a great number of valuable by-products, which are partly washed out of the gas, and partly extracted from the coal tar which separates from the gas as it passes through the mains and condensers. The tar can be separated into various fractions, partly of pure substances, partly of various mixtures of substances, and the various fractions provide raw materials for the manufacture of dyes, drugs, perfumes, photographic chemicals, explosives, and other valuable materials. Besides the tar, the gasworks produce ammonia for the alkali industry, and ammonium sulphate, which finds use in enormous quantities as a fertilizer. Another product is cyanide liquor, which is used for the preparation of Prussian Blue, and the extraction of gold from poor ores. The gas industry, in fact, is vital to the fulfilment of modern needs in many directions, and the utilization of all its possibilities is by no means complete.

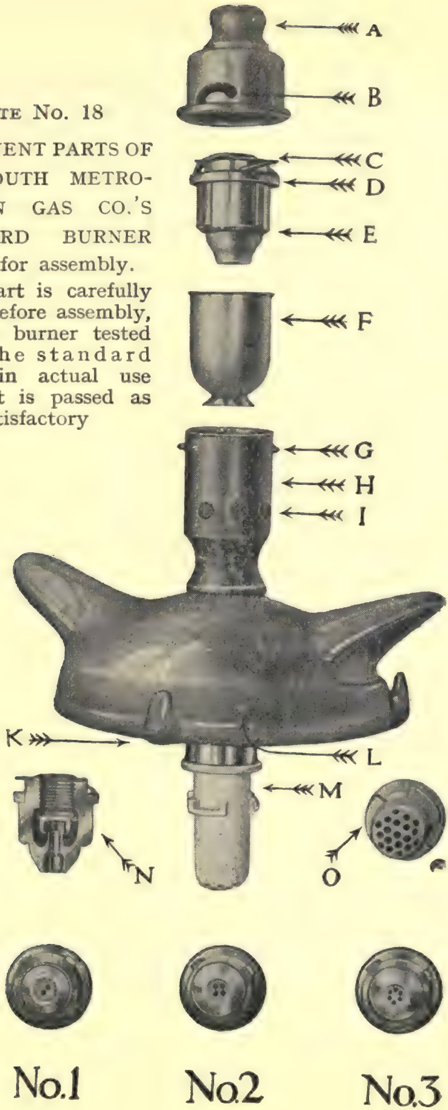
The gas produced by the ordinary methods of carbonization consists largely of hydrogen, which constitutes almost exactly one-half of the gas by volume. The next most important constituent is methane or marsh gas, the simplest compound of hydrogen with carbon, which is present to the extent of just over one-third by volume. Both these gases burn in air with almost colourless flames, which have practically no value for illuminating purposes when the gas is burned in the old flat-flame type of burner. The illumination in the flat flame is produced almost entirely from a small proportion—about 4 per cent—of gases rich in carbon. These are decomposed in the hot inner zone of the flame, yielding the tiny particles of carbon which at the high

PLATE No. 18

COMPONENT PARTS OF THE SOUTH METROPOLITAN GAS CO.'S STANDARD BURNER

Ready for assembly.

Every part is carefully tested before assembly, and the burner tested with the standard mantle in actual use before it is passed as satisfactory



temperature of the middle zone give rise to the light radiations. The remaining 10 or 12 per cent of the gas consists about equally of carbon monoxide, a compound of carbon and oxygen which burns with the rich blue flame frequently seen at the top of a fire which has almost burned through, and of nitrogen and carbon dioxide, which are incapable of combustion in air, and so contribute nothing to the value of the gas.

The standard of gas value was fixed originally by the lighting power when burned in the flat-flame burner, and gas is generally sold by the 1,000 cu. ft., the thermal value of which, as well as the proportions of inert compounds, and of such harmful constituents as sulphur compounds, is fixed by law. With the introduction of the incandescent mantle, the heating value of gas became of much more importance than its illuminating value when burned in the flat-flame burners, since the light given by the mantle depends on the temperature it attains, which depends on the heat of combustion of the gas.

For use in cooking and in gas fires also, the heating power of the gas is obviously the important consideration. During the war it became necessary to wash out from coal gas, by a special treatment, the small quantities of benzene and toluene which it normally contains, and which contribute materially to its illuminating power when burned in the old way, these substances being required for the manufacture of explosives. Where incandescent lighting was used, the loss of the benzene and toluene was not greatly felt, but the illuminating power in the old burners was materially reduced. This war experience made clearer the fact that under present conditions the heating value of gas is of more importance than its composition, provided objectionable substances are absent, and the first step

PLATE No. 19

GAUGING AND TESTING COMPONENT PARTS OF STANDARD BURNERS

Laboratories of the South Metropolitan Gas Company, London

has recently been taken in the direction of supplying gas at a cost based not on quantity, but on heating value. The new unit chosen has been called the Therm, and is based on the heat of combustion per cubic foot as determined at regular frequent intervals by the supplier. The new unit enables the gas supply undertaking to vary the composition of its gas within certain limits, since this can be done without affecting the heating value, and therefore to employ proportions of water gas and other gases of low illuminating power on the old standard.

The introduction of the new thermal value unit for gas supply has been largely due to the standardization work of the scientific staff of the South Metropolitan Gas Company, under the direction of the far-sighted and energetic chairman, Dr. Charles Carpenter. The ideal aimed at, and already achieved to a wonderful extent in practice, by the South Metropolitan Company is the supply of a gas of uniform heating value per cubic foot at an absolutely constant pressure. Given such a supply, it is possible, by using standard uniform burners and mantles, to ensure absolutely constant lighting values, and to maintain any desired standard of illumination continuously and uniformly, without the need of adjustment by the consumer. Incandescent lighting by means of gas becomes in this way as uniform and as certain as electric lighting.

To obtain such results, it is necessary not only to supply gas of uniform heating value at constant pressure, but to employ standard burners and mantles. The greatest care, therefore, becomes necessary in the manufacture of the burner. Plate No. 18 shows the component parts of the South Metropolitan Gas Company's standard burner, and Plates 19 to 22 show the laboratories in which the most exhaustive tests are

carried out before each burner is passed as satisfactory for sale to a consumer.

The adoption of the Therm as the unit of gas supply is proceeding steadily, and there can be no doubt that the process of standardization of gas lighting already initiated will be greatly developed and extended in the near future.

(3) ELECTRICITY. The first application of electricity to lighting was the arc lamp, which was attributed to the famous Sir Humphrey Davy, about the beginning of the nineteenth century. Until the development of the dynamo, the only sources of electricity were the voltaic current (after the Italian scientist, Volta, who devised the first electro-chemical cell), produced by chemical action in batteries or cells, and the static, obtained as intermittent high-tension discharges by friction between suitable substances, such as silk or cloth pads, and amber, glass, etc. Static electricity is unsuitable for application to power and lighting, and the numerous cumbrous cells required to give a current strong enough for practical use effectively restricted electric illumination by the voltaic cell to a few occasional, chiefly scientific, uses. During the eighteen-thirties, the great scientist Faraday discovered and investigated what are known as induced currents, by means of which kinetic energy, or the power to do work possessed by moving bodies in virtue of their motion, can be transformed into electric energy with much greater ease and convenience than by the friction which produces static electricity. Induced currents also allow of the reverse effect, i.e. the transformation of electrical energy into kinetic or motion energy, by means of which mankind has harnessed electricity to a thousand forms of work. To Faraday, therefore, modern civilization is indebted for the dynamo and the electric motor, the

importance of which, in relation to modern needs, equals that of fire itself to man's primitive ancestors.

The development and application of Faraday's work up to the stage at which the dynamo became a practical factor in the energy problem required half-a-century. The first Electric Lighting Bill was introduced into Parliament in 1882. Since that date development has been extremely rapid, and there are now innumerable generating plants supplying current for private, industrial and public purposes throughout the country. As in the case of gas, it can be stated that very few citizens in Great Britain, save in the remoter and more thinly populated districts, are not in a position to take advantage, if they so desire, of a convenient source of electricity for lighting and other purposes.

Faraday's discovery which led up to the dynamo was that if a simple coil of wire constituting a closed circuit, be moved within a magnetic field, or near to another coil carrying an electric current, and called the primary circuit, a current is set up in the former or secondary circuit, this current persisting as long as the motion continues within the sphere of influence. Since it is easy and simple to move a coil of wire, the continuous production of electricity became for the first time simple and easy, and its cost became that of securing the necessary motion under the required conditions. Naturally, in view of the diverse conditions under which dynamos are required to work, and the varying nature and pressures of current required, dynamo design has become a highly specialized study, though one which has been carried to so successful a conclusion that a moderately efficient dynamo to-day will transform 90 per cent of the mechanical energy supplied to it into electric energy at almost any desired pressure.

The unit in terms of which electricity is measured

Plate No. 20

FINISHING AND TESTING GAS SUPPLY REGULATORS FOR STANDARD BURNERS

Laboratories of the South Metropolitan Gas Company, London

and charged up to the consumer is the kilowatt-hour, or K.W.H., that is, 1,000 times the amount of energy carried by a current of 1 ampere at a pressure of 1 volt during an hour. From the known current consumptions per candle-power for the different types of lamp in general use, the current consumed over any period and hence the cost of the illumination may be easily calculated. The half-watt lamp, for example, is so called because the power consumed is only half of 1 watt per candle-power produced ; to burn a lamp of this type of 100 candle-power for one hour, therefore, will require 50 watt-hours, that is, one-twentieth of a unit. The carbon filament lamp, on the other hand, requires about 3 watts per candle-power, so that the same illumination by this kind of lamp would require 300 watt-hours, or three-tenths of a unit. The Nernst and metallic filament vacuum lamps are intermediate between these two in power consumption, and therefore in cost of running.

In modern generating stations, the motion of the revolving parts of the dynamo is obtained by gearing them directly to a steam-driven turbine. The cost of running such an installation during a few hours only of each day is extremely high for several reasons. In the first place, it is not practicable to raise steam in boilers by starting up from cold just when power is needed ; the boilers have to be kept under steam always, and this involves expenditure in coal and stokers' wages. Again, the installation must be big enough to meet any demands made upon it, even though the peak demand may last for a very short time only ; thus, in the early winter evenings, light is required not only in houses, but in shops, factories and other establishments, many of which may be closed when lighting-up time comes in summer. The dynamos in the generating station must be big enough to meet the heavy maximum winter

PLATE No. 21

CHECKING GAS CONSUMPTION BY STANDARD BURNERS, SOUTH METROPOLITAN GAS COMPANY'S WORKS

Every assembled burner must pass this test before it is considered satisfactory

load, yet they must be run whenever current is required. Now a dynamo only works efficiently when it is running near to its maximum load, that is, the cost of making current is unduly high unless the demand approaches the full capacity of the generator; further, small dynamos are much less economical than large ones, so that it does not pay to put in a large number of small units and work these as they may be required to meet changing demands, though, of course, most power stations have smaller generators to carry the smaller demands, and drop these out to bring larger sets into operation for the heavier demands. Again, engineers and staff must be paid full time rates whether the station is working at full load all the week or not, and large enough staffs must be maintained to allow of continuous working in shifts, day and night and week in and out.

For all these reasons the cost of generating electricity for lighting is unduly high, and therefore the suppliers offer special inducements to consumers who take current for purposes other than lighting, and especially where customers take current during the "off-load" period, i.e. when it is not required for lighting. Most companies offer special rates for current for power, cooking and heating, and these rates are especially low where the consumer undertakes not to use current between certain hours when the current is more especially needed for lighting.

(*b*) **The Cost of Lighting.** The accompanying table (page 112) shows roughly the cost of 1,000 candle hours for the various commoner forms of lighting under present conditions. A number of explanations are required before the table can be employed, and a number of assumptions which have been made in compiling it must be pointed out and discussed. In the first

PLATE NO. 22

PHYSICAL LABORATORY OF THE SOUTH METROPOLITAN GAS COMPANY, LONDON

place, the expression "1,000 candle hours" must be made clear. It is the amount of light which would be given by a 1,000 candle-power lamp burning for one hour, or by a 100 candle-power lamp burning for ten hours, or by ten 100 candle-power lamps burning for one hour, or by ten 20 candle-power lamps burning for five hours, and so on ; that is, it is the lighting value developed by lamps burning for such a time that the product of the combined candle-powers and the time of burning expressed in hours is 1,000.

In comparing the cost of the various forms of lighting, some such standard must be used, though in practice it must be applied with some caution. A consumer will generally expect and demand a better light from an incandescent mantle burner or a ½-watt lamp, for example, than from an oil lamp, so that 1,000 hours illumination by these different methods will not necessarily mean the same number of candle hours in each case. The figures given for cost per 1,000 candle hours, however, will give the consumer some idea of the cost for a given time and candle-power, and by dividing the combined candle-power of his fittings into 1,000, he will obtain as quotient the number of hours light he will get for the cost given.

In Column 1 of the table, under the heading "Source," are given the prices which have been employed for the various sources of light for the purposes of the calculation. Good grades of lighting oil can be obtained generally for about 1s. 6d. per gallon, though for small quantities purchased at retail stores, prices may be somewhat higher. The figure of 6s. per 1,000 cubic foot of gas, and that of 9d. per Board of Trade unit for electricity, can be taken as approximate values only—in big towns or in favoured localities the costs may be less, in small towns, or under adverse conditions, they

may be higher. By substituting the values obtaining in his own case, and with the aid of the figures in Column 4, which show the units required per 1,000 candle hours by the various methods of lighting, the consumer can at once calculate the actual cost under his own conditions.

The data from which the costs have been calculated, shown in Column 3 of the table, have been selected from the records of many observers and are trustworthy for the conditions under which they were measured. These figures, however, do not apply to all conditions. If the wick of an oil lamp is allowed to get clogged up, and is left untrimmed, while the lamp itself is allowed to become dirty so that the air supply is restricted, and the chimney intercepts the light instead of transmitting it, its light will naturally be greatly reduced, and the cost per 1,000 candle hours much increased. In the case of gas, alterations in the pressure and partial stoppages of the burner will reduce the light, whilst with an incandescent mantle, bad adjustment of the gas-air mixture or of the position of the mantle in the flame will give bad results. Electric lights are very susceptible to slight changes in the voltage of the supply, slight increases giving much brighter lights (with corresponding reduction in the effective life of the lamp), whilst slight falling off of the pressure causes a relatively very great diminution in the illumination. The figures given are for standard lamps, which are designed to give a life of 500 to 800 hours at the specified voltages. The age of filament lamps and of incandescent mantles is also of importance—the normal life of the mantle is 700 to 900 hours, of the filament generally rather less—and generally the light-giving power begins to diminish considerably after the normal period has been completed, with equivalent rise in cost.

TABLE SHOWING COST OF LIGHTING PER 1,000 CANDLE HOURS BY THE COMMONER METHODS

(Reference to the Text should be made when using the Table)

Source.	Method of Illumination.	Data for Calculation.	Units Required per 1,000 Candle Hours.	Cost in Pence per 1,000 Candle Hours.
1. OIL Paraffin at 1s. 6d. per gallon.	(*a*) Small Wick Lamp—poor efficiency	100 grains oil per candle hour	14·3 pints	32·2
	(*b*) Medium Wick Lamp—high efficiency	40 ,, ,, ,,	5·7 ,,	12·82
	(*c*) Incandescent Lamp—medium size	12 ,, ,, ,,	1·7 ,,	3·82
	(*d*) Incandescent Lamp—big size	1 pint oil per 1,000 candle hours	1 pint	2·55
2. GAS at 6s. per 1,000 cubic feet.	(*a*) Flat or Batswing Burner	$2\frac{1}{2}$ candles per cubic foot	400 cubic feet	28·8
	(*b*) Argand Lamp	3 ,, ,, ,,	333 ,, ,,	24·0
	(*c*) Regenerative Lamp	9 ,, ,, ,,	111 ,, ,,	8·0
	(*d*) Incandescent Lamp—Upright Mantle	18 ,, ,, ,,	55 ,, ,,	4·0
	(*e*) Ditto—Inverted Mantle	20 ,, ,, ,,	50 ,, ,,	3·6
	(*f*) Ditto—High Pressure—Small	30 ,, ,, ,,	33 ,, ,,	2·4
	(*g*) Ditto—High Pressure—Large	36 ,, ,, ,,	28 ,, ,,	2·0
3. ELECTRICITY at 9d. per kilowatt-hour.	(*a*) Carbon Filament	3 watts per candle-power	3·00 kw.-hours	27·0
	(*b*) Osram Filament	1·5 ,, ,, ,,	1·50 ,, ,,	13·5
	(*c*) Tungsten Filament	1·25 ,, ,, ,,	1·25 ,, ,,	11·25
	(*d*) Half-watt Lamp	0·5 ,, ,, ,,	0·50 ,, ,,	4·5
	(*e*) Arc Lamp	0·33 ,, ,, ,,	0·33 ,, ,,	3·0
	(*f*) Mercury Vapour Lamp	0·25 ,, ,, ,,	0·25 ,, ,,	2·25

The values for the data used depend also on the distribution of the light, and on the shades or reflectors employed. To obtain comparative figures for the table, what are known as the mean hemispherical values have been taken for unshaded lights, for it is at once obvious that no general allowance can be made for the effect of shades and reflectors, or for the distribution of light in particular directions.

Turning now to the relative costs given in Column 5 in pence per 1,000 candle hours, it is seen that an efficient oil lamp of the ordinary flat or circular wick type costs nearly 13d., which is considerably below the costs for the flat-flame gas burner, and the carbon filament lamp. In general, a considerably lower standard of lighting is required when oil lamps are employed, so that in practice this form of illumination is amongst the cheapest. The influence of the incandescent mantle on the cost of oil illumination is very striking, the cost of 1,000 candle hours with oil lamps of the incandescent type being not much more than a quarter of the cost with the ordinary lamp. For very large installations, such as are employed in lighthouses, the cost of the oil incandescent lamp is as low as 2¼d. per 1,000 candle hours.

For gas the effect is even more striking, the cost with the inverted mantle being only about one-eighth of the cost with the old batswing burner. The big high pressure incandescent gas lamp gives probably the cheapest form of lighting under average conditions, the cost being only 2d. per 1,000 candle hours. With electricity, the reduction in cost by the introduction of the metallic filament lamp is considerable, but does not bring the figure down to the level of the incandescent gas light. Even the half-watt lamp, the most recent development in the direction of cheapness and efficiency,

is on the average more expensive than the inverted mantle. The vapour lamp is the cheapest form of electric lighting, and affords a promising field, if light of a more acceptable character can be produced.

The figures given in the table take no account of the cost of fittings, mantles, electric lamps, and so on. Here, again, gas as a rule has the advantage in respect of cost, for the mantle is considerably cheaper than the electric lamp, and has a somewhat longer life.

(*c*) **Other Considerations.** After the two chief considerations, source of supply available and cost, the next most important factor influencing the choice of a lighting system will generally be convenience ; indeed, in very many cases, this factor will be considered before that of cost. There is no question as to the desirability of the form of illumination which requires merely pressure on a switch, with no further adjustment of any kind, to secure immediate and effective operation. Efforts have been made to install such semi-automatic devices in connection with gas incandescent lighting, but they have not been altogether successful, and for the present electricity undoubtedly takes precedence in this direction, at least for domestic lighting. The by-pass system has been successfully applied to shop and street lighting by gas, both for the high pressure and the ordinary upright mantle fitting, and many districts have street lighting installations of this kind which leave nothing to be desired.

The question of the relative effects on health of gas and electric lighting has been exhaustively examined. A long series of experiments was carried out with subjects under similar conditions in similar rooms lighted respectively by carbon filament lamps and inverted incandescent burners of about the same candle power. Practically no perceptible differences of the slightest

importance were found. The change in the composition of the air in closed rooms is far more due to the persons present than to any gas burned, and the amount of carbonic acid gas produced by any ordinary gas burners is so small as to be of no effect. The mental fatigue of the subjects seemed to be slightly more after exposure to gaslight than after exposure to electric lighting, but gas had less effect than electric light on the sensitiveness of the eye to light. Even the greater heat given off by gas burners did little to raise the temperature of the room, probably because the hot air and products of combustion rise to the ceiling and give up their heat there.

The rise of hot air and products of combustion from gas burners to ceilings introduces a further consideration, since the effect on the ceiling becomes apparent after a time. The heat evolved by the electric lamp is generally less than that evolved by gas lights, and certainly the effect on ceilings is far less. The half-watt lamp, however, disengages very important quantities of heat, which may have serious effects on shades and perishable parts of fittings.

The question of the danger involved in the use of any particular form of lighting is one that generally receives little attention, for the reason that with ordinary care it so seldom arises. Probably the use of oil involves the greatest risk, since any accident or carelessness may result in fire. The chief risk in the use of gas is due to the possibility of leaks, which may cause asphyxiation or explosion, though neither of these can occur if the very simplest dictates of common sense are obeyed. Most gas consumers know better than to search for a leak with a candle, and few are so indifferent to the necessity of ventilation as to remain in rooms so sealed up as to make a possible leakage of gas dangerous

to health. With regard to electric lighting, practically the only risk, that of fire arising from overheating of wires and fittings, is reduced to an almost negligible minimum by the Board of Trade regulations, and accidents arise very seldom where these are properly observed.

In addition to all the considerations outlined above, the great factor of individual taste influences the selection of a given system of lighting. Some people find electric light too glaring ; some find incandescent light unpleasant in colour. Where, as in most large towns, both gas and electricity are available, it will often be an individual preference for one or either type of light which will decide the choice. For shop and street lighting, the possibilities of distribution are of importance. One salesman finds electricity enables him to get a linear distribution of light round the edges of his windows and shop fittings ; or possibly his goods make a greater appeal under the soft radiance of the incandescent mantle. For street lighting the questions of shadows and of minimum distances between standards may become deciding factors. Each application, in fact, may introduce details peculiar to itself which will affect the choice.

CHAPTER VII

LIGHTING AND THE ENERGY PROBLEM

THE fact that Light is a form of Energy, and that our modern requirements of artificial light make a considerable demand on the energy resources of the universe, brings us to the last and widest aspect of our subject. The actual proportion of the world's energy supply which is transformed into light is, in fact, extremely small, but owing to the wastefulness of our methods of transforming the energy with which Nature has supplied us, it is by no means negligible. Even the arc lamp, the most efficient practical form of lighting from the energy point of view, has a light efficiency of less than 15 per cent, that is of the radiations produced from the energy supplied less than 15 per cent are light radiations. For the flat-flame gas burner and the ordinary oil lamp the figure is between 2 and 3 per cent. Nor do these figures reveal the full extent of the loss, for the arc lamp transforms into radiant energy only about one-half of the energy supplied to it, whilst the oil lamp transforms only about one-twentieth of the heat of combustion of the oil into radiations.

Taking the whole position, then, the arc can transform into light energy only 15 per cent of one-half, that is only about 7 per cent of the electrical energy supplied to it, whilst the oil lamp reproduces as light energy only about $2\frac{1}{2}$ per cent of one-twentieth, that is only about one-eighth of 1 per cent of the chemical energy contained in the oil and oxygen which are consumed in it. These figures appear to denote that the arc lamp is very much more economical in its use of

energy than the oil lamp, but they are misleading to some extent. We have no practicable sources of electric energy as such in Nature in this country—at least, none are being utilized, so that the electric energy supplied to the arc must be obtained from some other form of energy, and since our present methods of generating electricity from coal or oil are also relatively inefficient, the energy balance in favour of the arc is not so great as it at first appears.

Let us carry the discussion somewhat further, and bring the incandescent light into consideration. One thousand cu. ft. of ordinary coal gas produce on combustion heat equivalent roughly to 500 million foot-pounds of work ; that is if it could be transformed without loss into mechanical work the heat produced by burning 1,000 cu. ft. of gas would raise a weight of 500 million pounds, say roughly a quarter of a million tons, a height of 1 ft. against the force of gravity. But our methods of transforming heat energy into mechanical energy are not and cannot be very efficient. If we burned our 1,000 cu. ft. of gas in a gas engine, we should get an energy efficiency of about 15 per cent only, that is of our 500 million foot pounds we should be able to use only about 75 million foot pounds, equivalent roughly to 40 horse power acting for 1 hour. If now our gas engine were used to drive a dynamo we could transform about 85 per cent of our 40 horse power hours, or, say, about 64 million foot pounds, into electrical energy ; this would give us in the arc about 32 million foot pounds of radiant energy (the remainder being lost again as sensible heat), of which about 15 per cent, or nearly 5 million foot pounds, would be in the form of light, and would give us about 75,000 candle hours.

From 1,000 cu. ft. of coal gas, therefore, which by

burning gives heat equivalent to 500 million foot-pounds, we have obtained as light only about 5 million foot pounds, an energy efficiency of only 1 per cent. Also by this cycle, we have obtained from our 1,000 cu. ft. of gas 75,000 candle hours. If, now, we burned this quantity of gas directly in a high pressure incandescent lamp, we should obtain 30,000 candle hours, whilst an ordinary inverted incandescent lamp would give us 20,000 candle hours. It is evident, then, that in spite of the various transformations we have obliged our energy to pass through in the case of the gas engine—dynamo—arc-lamp cycle, our losses of energy from the light-producing point of view have been only half as great as if we had burned the gas directly in an inverted high-pressure incandescent system. The superiority of the electric arc to the gas burner from the light efficiency point of view therefore remains considerable, even if account is taken of the losses incurred in generating the electricity and supplying it to the arc.

The question now arises, How are these losses of energy incurred, and what do they signify? Energy, like matter, is indestructible, and the quantity of energy in the universe cannot alter. Since the stars are too far away to send us much energy, and the moon and planets have none of their own to give us, the energy resources of our world are confined to what we already have, and what we receive from the sun. But though we cannot destroy energy, we can render it useless and unavailable. The lowest form of energy is heat. Whilst every other form of energy is easily and completely transformed into heat, it is not always easy to transform heat into other and more valuable forms of energy, and it is never possible to do so completely.

The extent to which heat can be transformed into other forms of energy is determined by the limits of temperature between which the working medium can be employed. In the steam engine, for example, the limits are the temperature reached by the steam at the pressure of the boiler and the temperature of the exhaust steam, and since these two in practice are always close together relatively little of the heat is transformed into work. In the internal combustion engine, the limits are the temperature of explosion and the temperature of the exhaust gases, and since these are farther apart, a much higher proportion of the heat is obtained as work, that is the energy efficiency is much greater. It follows, then, that heat, *per se,* is unavailable as a source of mechanical energy, and without differences of temperature no work can be obtained from ordinary or sensible heat. Heat can, however, appear in another form, known as radiant heat. This is the form in which the sun's energy reaches us. In this form, heat is available for work, since in meeting any solid substance it is transformed into sensible heat, which at once produces a difference in temperature between the body receiving the rays, and surrounding objects.

Not only is it impossible, with the means at our command, to transform heat completely into other forms of energy such as electricity, mechanical or kinetic energy, light, chemical energy, and so on, but, in practice, every transformation of these other and higher forms of energy produces some heat—at every endeavour to make the energy more useful to us, some of it slips back, as it were, and is degraded down to heat. Since this heat produced in energy transformations tends to raise the mean temperature of the universe, and therefore to diminish the temperature limits

between which our heat engines can work, every transformation of energy not only involves direct loss as heat, but makes it an infinitesimal bit more difficult to obtain further supplies of useful energy from heat engines. Energy, therefore, is being continuously degraded or rendered unavailable, and since the quantity in the universe is fixed—well, that is the Energy Problem. Even the most pessimistic, however, need not despair of the universe. Our knowledge, though yet small, is growing, and we shall beyond doubt eventually discover methods of utilizing the natural conditions of the universe to much greater advantage than we yet dream of.

The energy resources of the earth, together with the heat and light we receive from the sun, are truly enormous. They consist firstly of the vast quantities of chemical energy stored up in our coal and oil deposits by the action, direct and indirect, of the sun's heat in past ages. This energy we transform into high temperature heat by burning the coal and oil in air, and the high temperatures reached by this means we utilize, very inefficiently at present, but with gradually increasing knowledge, to drive our various external and internal combustion engines. Next we have the power of waterfalls and the tides, the first derived directly from the sun's heat, which evaporates moisture from the oceans and lifts it for us to form clouds, which give the rain which forms the rivers, whilst the second, the energy of the tides, is derived from the energy of the spinning motion of the earth and the attraction of gravity exercised on the waters of the oceans by the sun and moon. The use of waterfalls as a source of power, therefore, is extremely economical, in that we are really using energy derived at the present time from the sun, that is our energy income, whereas by burning coal and oil we are

drawing on power stored up for us in past ages, that is our energy capital.

The utilization of tidal energy has at present hardly been attempted, though the possibilities, under favourable conditions, are enormous. A scheme recently put forward to employ the tidal movements of the water of the Severn estuary postulates the continuous development of half-a-million horse-power in this way, at a cost of less than one-third that of the cheapest public supply in the country. Since tidal energy is derived from the spinning motion of the earth, the effect is to cause a gradual diminution of that motion, that is to slow up the rate of revolution of the earth about its axis, and so to lengthen the present 24-hour day and night cycle. The complete day and night cycle is, in fact, increasing in duration by a small fraction of a minute in each century. It is obvious that on this basis no very drastic alteration of our conditions of life need be feared for the present, and tidal energy, once harnessed, could be regarded as available for an indefinite time.

The sun's direct heat may also be used by concentrating the rays by systems of lenses and utilizing the high temperature obtained by focusing the radiant heat, or advantage may be taken of the currents it gives rise to in the air, as in windmills and sailing ships. An enormous possibility is opened up by the proposal to utilize the sun's heat in tropical regions to raise great harvests of suitable plants, the products of which may be fermented to produce alcohol and other combustible substances for use in internal combustion engines. Proposals to produce power alcohol on these lines have been recently stimulated by the great increase in the demand for petrol, which is threatening to exceed the world's present production. Such methods have

the advantage that they would use energy income, at present going to waste, and help to conserve our energy capital of coal and oil. Again, the sun's heat, in virtue of the inclination of the earth's axis to the plane of the ecliptic, gives rise to the extremes of temperature existing at the poles and the equator, and the possibility of employing these temperature differences, though remote enough at present, may be numbered amongst our potential resources.

The internal heat of the earth, a heritage dating from the time when the whole solar system was a nebulous incandescent mass of vapour, has also been suggested as a source of energy. Beneath its solid crust of some 30 to 50 miles in thickness, the mass of the earth must still be at incandescent heat, constituting an incalculable reserve of energy. In volcanic regions, power has, in fact, been derived from this source by utilizing the steam generated from percolating moisture. Knowledge, and courage in applying it, will in all probability find means to tap this inexhaustible fund in the future.

Another tempting vision of physical science is the possibility of employing atomic energy. The power locked up in the more complex atoms is vast beyond dreams. Though our present knowledge offers no hope of the possibility of being able to unlock and control this unlimited reservoir of power, the very realization of its existence is a tremendous step forward. Some of the complex elements, the group of radioactive substances, are even now breaking up in Nature, liberating energy continuously. The element radium, for example, is liberating energy at a rate sufficient to bring to the boiling point its own weight of water several times daily, and will go on doing this practically for ever, its breaking up being so slow that its

weight takes about 1,500 years to diminish by half. Only a few ounces of radium are believed to be available in the whole earth, but its value lies not so much in itself as in the new field of knowledge it has opened up. Could mankind but discover how to originate and stop at will this process of atomic splitting-up, the Energy Problem would cease to exist, power would be available for lighting and heating and for every kind of purpose to an unlimited extent ; in a few generations the need to work would have been reduced to a minimum so small that life would hold no interest but the doubtful pleasure of enjoyment, and with the inauguration of a veritable Millennium on the earth itself, mankind would have to recast entirely its conditions of existence, or rapidly disappear from the world.

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